CHAPTER IV
MAJOR WATERBODIES OF THE GREAT WATERS:
AN OVERVIEW OF PROGRAMS AND EFFORTS ADDRESSING ATMOSPHERIC DEPOSITION

Section 112(m) of the Clean Air Act specifically designates the Great Lakes, Lake Champlain, Chesapeake Bay, and certain other U.S. coastal waters as waterbodies EPA is to consider in identifying and assessing atmospheric deposition of hazardous air pollutants (HAPs) to the Great Waters. Researchers have found that the Great Waters have been affected by metals, pesticides, toxic chemicals, and nutrients that enter the waters through different pathways, including atmospheric deposition.

This chapter presents information currently known about contamination occurring at the individual Great Waters, including problems or issues that challenge each waterbody, followed by discussion of current strategies or efforts to respond to these concerns. Most of the information has been generated from activities occurring at the Great Lakes and Chesapeake Bay. In the Great Lakes, several initiatives have been introduced in recent years, ranging from research projects to gather quantitative estimates of atmospheric loadings to regulatory and voluntary activities promoting reduction of loadings to the waterbody. Efforts at Chesapeake Bay have focused on developing models to improve characterization of nitrogen and toxic contaminant loadings, as part of major reduction strategies. Research is more limited for Lake Champlain and for the other coastal waters. In these waterbodies, smaller-scale investigations have been carried out to study certain pollutants of concern in their respective waterbodies, and in many cases, comprehensive strategic plans have been developed to address contamination issues.

This chapter is organized by sections on each of these major waterbodies of the Great Waters and divided accordingly:

- Section IV.A presents information available on atmospheric deposition of persistent toxic pollutants into the Great Lakes and the many programs to characterize and reduce loadings;

- Section IV.B describes Lake Champlain and current research to assess atmospheric mercury deposition in the basin;

- Section IV.C discusses the deposition of nitrogen and toxic pollutants to Chesapeake Bay and the related monitoring and modeling efforts; and

- Section IV.D provides an overview of U.S. estuary programs and some major efforts to characterize loadings of nitrogen and toxic pollutants to coastal waters.

Although this chapter describes current data and programs specific to the subject waterbody, much of the information is relevant to other waters as well. For example, those interested in smaller estuaries will gain insight from information presented in the Chesapeake Bay section.

The Great Lakes and Lake Champlain represent two important freshwater systems in the United States. Lakes are sensitive to pollution inputs because they lack any dominant, unidirectional flow, and as a result, there is a slow change of water and a resulting retention of pollutants.

The Great Lakes contain approximately one-fifth of the world's supply of fresh surface water. These lakes have played a vital role in the history and development of the United States and Canada. They are stressed by a wide range of pollution sources associated with the large urban centers located on their shores. Because the Great Lakes system is a relatively closed water system (very large volume, with relatively small water inflows and outflows), many of the pollutants that reach the Great Lakes remain in the system for extended periods of time. For example, Lake Superior replaces all the water in the lake every 191 years, Lake Erie every 2.6 years.

Lake Champlain is located in the northeastern United States, shared by the states of New York and Vermont and the Province of Quebec. Although much smaller in surface area than the Great Lakes, Lake Champlain is still one of the largest freshwater lakes in the United States and its natural resources are important to the local economy. The Lake Champlain basin, or watershed, is much larger relative to its water surface area than the Great Lakes, and so watershed throughput is much more of an issue for Lake Champlain. Toxic pollutants are an issue of wide public concern in the Lake Champlain Basin, due in large part to fish consumption advisories for PCBs and mercury issued by both New York and Vermont, and the potential impact on drinking water and the Lake's many other uses.

"Coastal waters," for the purposes of CAA section 112(m), are defined as those estuaries designated for the National Estuary Program (pursuant to section 320(a)(2)(A) of the federal Water Pollution Control Act) or designated for the National Estuarine Research Reserve System (pursuant to section 315 of the Coastal Zone Management Act). Chesapeake Bay is identified by name in section 112(m).

Estuaries occur where rivers empty into the ocean, mixing together fresh water and salt water, and creating an ecosystem distinct from, and often more productive than, either fresh or salt water systems. Estuarine waters include bays, sounds, marshes, swamps, inlets, and sloughs. These environments are characterized by varying degrees of salinity, high turbidity levels, and complex water movement affected by ocean tides, river currents, and wind. Estuaries are critical coastal habitats that serve as spawning grounds, nurseries, shelters, and food sources for many different species of shellfish, fish, birds, and other wildlife. The leading environmental problems in estuarine systems at present are eutrophication,[10] contamination by toxic chemicals and pathogens (disease-causing organisms), over-harvesting, and loss of habitat.

In 1975, Chesapeake Bay became the nation's first estuary to be targeted for protection and restoration. Over the past decade, other coastal programs, such as the National Estuary Program, the National Estuarine Research Reserve System, and the Gulf of Mexico Program, have been established to protect and restore water quality and living resources in U.S. estuaries and coastal waters. Chesapeake Bay was also among the first estuaries where atmospheric sources of nutrients and toxic pollutants were recognized as significant inputs to the waterbody. Recently, research on other U.S. coastal waters has begun to evaluate the loadings of nutrients and toxic pollutants to their watersheds from atmospheric sources. The Great Waters program has focused primarily on Chesapeake Bay for estuarine issues, and has found that information developed for this waterbody is generally applicable to several other East Coast estuaries, when

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[10] As discussed in Section II.D and in this chapter, eutrophication is over-enrichment of waters that is characterized by algae blooms, turbid waters, and low or no dissolved oxygen conditions.

adjustments are made for respective waterbody's physical, chemical, and geomorphological characteristics.

IV.A The Great Lakes

The Great Lakes, comprised of Lakes Superior, Michigan, Huron, Erie, and Ontario, are an important part of the physical, cultural, and industrial heritage of North America (see Figure IV-1). The Great Lakes ecosystem, the interacting components of air, land, water, and living organisms, including humans, is one of the largest surface systems of freshwater on earth. This ecosystem contains 18 percent of the world's freshwater supply and 95 percent of the surface freshwater within the United States. Only the polar ice caps and Lake Baikal in Siberia contain more freshwater than the Great Lakes. By virtue of their size, the Great Lakes affect the climate of the surrounding region. Areas of Michigan, Ontario, and New York generally have warmer, though snowier, winters than other parts of North America at similar latitudes because, as a result of little continual current, the lakes retain a large amount of heat. In spring and early summer, the lakes are slow to warm, thereby keeping the nearby land areas cool.

The Great Lakes sustain a rich diversity of fish, birds, and other wildlife. Native fishes important for commercial and recreational harvest include lake trout, lake whitefish, and walleye. Non-native species such as smelt, white perch, brown trout, rainbow trout, and several Pacific salmon species also contribute substantially to the total annual fish harvest. Approximately three million waterfowl follow the Atlantic and Mississippi flyways through the Great Lakes basin each year. Native animals include deer, fox, moose, wolves, beaver, mink, and muskrat. In addition, the Great Lakes ecosystem supports more than 100 globally endangered or rare species (Nature Conservancy 1994).

Economic Highlights of the Great Lakes

- Approximately 11% of total employment and 15% of manufacturing employment of combined U.S. and Canadian workers are located in the Great Lakes basin.

- Trade between Canada and the eight Great Lakes States in 1992 was valued at $106 billion (56.2% of the U.S.-Canada total).

- An estimated 900,000 to 1 million U.S. and Canadian boats operate each year, resulting in a direct spending impact on the regional economy of more than $2 billion.

- About 2.55 million U.S. anglers fish the Great Lakes; total trip-related and equipment expenditures were $1.33 billion in 1991.

Source: Allardice and Thorp 1995.

The Great Lakes basin is home to more than 33 million people, including 10 percent of the U.S. population and 25 percent of the Canadian population. Over 23 million of these people depend on the Great Lakes for drinking water. Industries use the water to make products, to cool manufacturing processes or power generation equipment, and to ship raw materials and finished products. Residents and visitors alike enjoy an abundance of recreational activities, including boating, swimming, fishing, sightseeing, camping, and hiking.
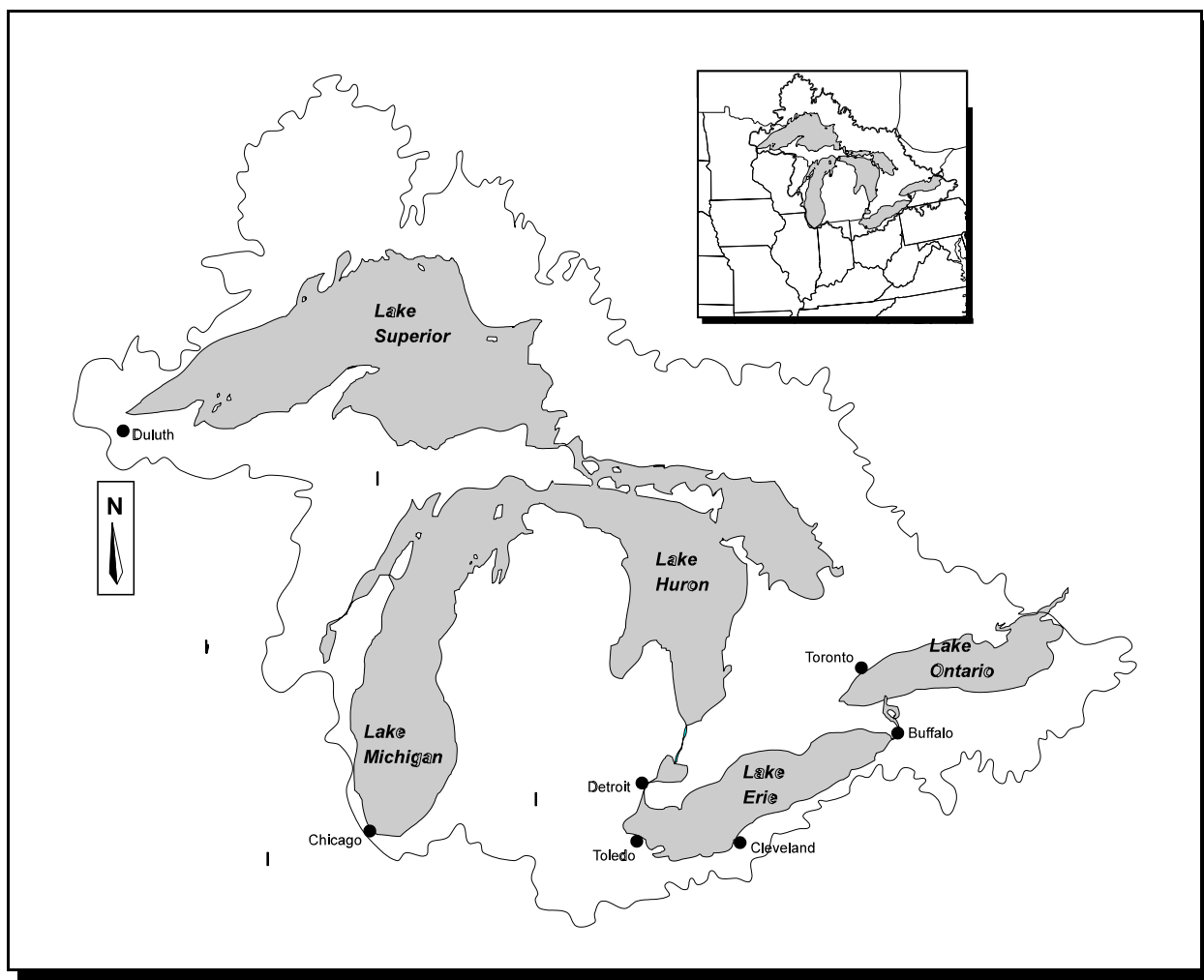
The concentration of human activities in the Great Lakes basin (e.g., manufacturing, transportation, agriculture, fishing) imposes stresses on the ecosystem and has prompted significant concerns for the health and well-being of the human residents. Many of the major stressors and resultant effects were documented in the First Great Waters Report to Congress. The current report builds on this information and presents some of the potential problems that may affect the Great Lakes basin from the perspective of the CAA, and major programs that are underway to address those problems.

FIGURE IV-1
Great Lakes Basin

Physical Features of the Great Lakes						
	Superior	**Michigan**	**Huron**	**Erie**	**Ontario**	**Totals**
Volume (km^3)	12,100	4,920	3,540	484	1,640	22,684
Maximum Depth (meters)	406	282	229	64	244	NA
Water Area (km^2)	82,100	57,800	59,600	25,700	18,960	244,160
Land Drainage Area (km^2)	127,700	118,000	134,100	78,000	64,030	521,830
Retention Time (years)	191	99	22	2.6	6	NA

NA = not applicable

The remainder of Section IV.A presents:

- Current knowledge and recent measurements of atmospheric levels and deposition of toxic pollutants to the Great Lakes;

- Information on major activities/programs currently in progress to assess atmospheric deposition of air pollutants to the Great Lakes;

- Efforts supported by the United States, as well as Canada, to reduce and mitigate atmospheric emissions in the Great Lakes basin; and

- Brief discussion on current information gaps, and future research needs to improve understanding of atmospheric deposition of pollutants into the Great Lakes.

Atmospheric Deposition of Great Lakes Contaminants

Hundreds of anthropogenic chemicals have been identified in the Great Lakes ecosystem. High levels of certain bioaccumulative pollutants remain in certain fish and wildlife species, and fish advisories have been issued by many Great Lakes states for several pollutants of concern, specifically chlordane, dioxins, mercury, PCBs, and toxaphene (specific advisories are listed in Appendix B). For example, although concentrations of PCBs and DDT in Lake Michigan lake trout are currently about one-tenth of those of 20 years ago (Figure IV-2), the concentrations are still at levels that warrant issuance of public health advisories regarding the consumption of these fish. Advisories may especially apply to specific subpopulations, such as children and women who are pregnant or anticipate bearing children.

The pollutants of concern have been associated with health problems in certain fish and wildlife species, although with the decline of some pollutant levels, many species may be recovering. For example, the number of double-crested cormorants living on the Great Lakes has increased more than 20-fold during the past 15 years. Prior to this, numbers of these fish-eating birds declined during the 1970s due to reproductive failure from DDE-induced egg shell thinning. Health problems persist for fish and wildlife in certain locations, particularly in waters

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Common Terminology for Pollutant Movement in a Waterbody

FLUX

Transport of a chemical across an interface (e.g., between air and water) for a given area and time, accounting for both inputs and outputs. Net flux is equal to all positive loadings minus all negative loadings.

INPUTS (positive loading)

Wet Deposition: Gases and particles carried in precipitation (rain, snow, sleet) and deposited on land and water surfaces.
Dry Particle Deposition: Pollutants, bound to particles, deposited on land and water surfaces in the absence of precipitation.
Gas Absorption: Gaseous form of pollutants crossing air-water interface into the water (portrayed as a positive number in a flux calculation).
Waterborne Discharge: Pollutants discharged directly to water (e.g., by industrial discharge, urban storm-runoff).
Tributary Loading: Pollutants entering waterbody through connecting channels, streams, and rivers.

OUTPUTS (negative loading)

Volatilization or Gas Evasion: Gaseous form of pollutants crossing air-water interface into the air (portrayed as a negative number in a flux calculation).
Sedimentation: Settling of particles by gravity to bottom sediments.
Outflow: Pollutants flowing with water out to rivers or to the ocean.

Figure IV-2
PCBs and DDT in Lake Trout from Lake Michigan
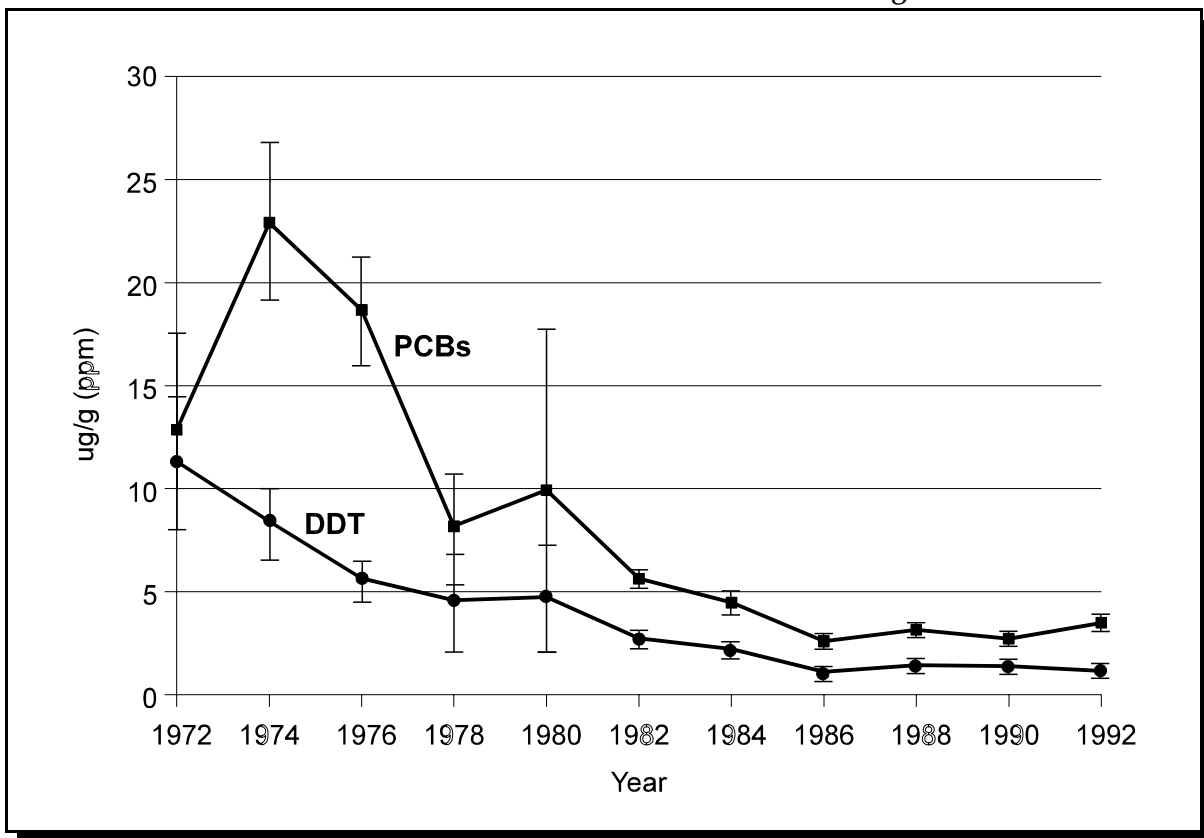
with highly contaminated bottom sediments, and for predators high in the food web, such as lake trout, mink, and bald eagles.

During the 1980s, studies in the Great Lakes showed that atmospheric deposition may be a major route of introduction of a number of pollutants to the Great Lakes. For example, atmospheric transport of toxaphene was implicated when the insecticide was found in fish in Lake Siskiwit, located on an island in Lake Superior Because the elevation of Lake Siskiwit is above that of Lake Superior, it does not receive any groundwater from Lake Superior and thus pollutant input. This pesticide was used mainly on cotton crops in the southern United States, prior to its cancellation in 1982 (McVeety and Hites 1988).

As a result of this and other findings, the United States and Canada established a joint monitoring network called the Integrated Atmospheric Deposition Network (IADN). The IADN is designed to assess the magnitude and trends of atmospheric deposition of target chemicals to the Great Lakes, and to determine emission sources wherever possible. The program responds to the Great Lakes Water Quality Agreement (GLWQA) between the United States and Canada, specifically to the needs of Annex 15 which addresses issues concerning airborne contaminants in the Great Lakes basin. A more detailed discussion of the rationale, design, and results of the IADN, as well as the uncertainties that exist in calculating atmospheric deposition estimates, is presented in the following subsection (Program Actions to Characterize Atmospheric Contamination in Great Lakes).

The first consensus data report for IADN (Eisenreich and Strachan 1992) revised and improved the very broad estimates of atmospheric deposition of toxic contaminants that were previously compiled (Strachan and Eisenreich 1988). More recent data were incorporated into deposition estimates for 1994 and compared to the earlier results (Hoff et al. 1996), as shown in Table IV-1. A general decline in some pollutant levels is suggested from the estimates in Table IV-1. Average estimated atmospheric loadings of certain pollutants to the five Great Lakes between 1991 and 1993 are presented in Table IV-2. The data in Tables IV-1 and IV-2 may not be comparable because the estimates represent measurements at different time frames. It is important to recognize that the values presented in these tables are based on preliminary data and limited samples. Furthermore, contributions from water inputs and outputs are not included. As such, overall loadings to the lakes cannot be established from these data alone.

Atmospheric loadings of pollutants are calculated using atmospheric concentration data gathered by IADN and estimates for various parameters such as lake surface area. The wet deposition data are based on estimated annual precipitation rates, and do not use actual rainfall amounts. Although uncertainties exist for the parameters which can lead to some degree of error, the atmospheric deposition estimates are based on the best scientific data currently available.

The remainder of this subsection presents atmospheric concentration and deposition data collected primarily from IADN on some pollutants of concern, as well as information on current trends of pollutant deposition. The pollutants of concern discussed include PAHs, PCBs, pesticides (e.g., DDE, DDT, lindane, toxaphene), and trace metals (e.g., lead, mercury). PCBs,

TABLE IV-1
Atmospheric Loading Estimates for Selected Pollutants (kg/year) in the Great Lakes

Pollutant of Concern	Superior	Michigan	Huron	Erie	Ontario
PCBs[a] (Wet and Dry)					
1988	550	400	400	180	140
1992	160	110	110	53	42
1994	85	69	180	37	64
PCBs[a] (Net Gas Transfer)[b]					
1988	-1900	-5140	-2560	-1100	-708
1994	-1700	-2700	--	-420	-440
DDT (Wet and Dry)					
1988	90	64	65	33	26
1992	34	25	25	12	10
1994	17	32	37	46	16
DDT (Net Gas Transfer)					
1988	-681	-480	-495	-213	-162
1994	30	67	--	34	13
Benzo(a)pyrene (Wet and Dry)					
1988	69	180	180	81	62
1992[c]	120	84	84	39	31
1994	200	250	--	240	120

-- Not determined or reported.
[a] Data presented for PCB congeners 18, 44, 52, and 101 (each with 3-5 chlorines in chemical structure).
[b] The convention is to assign a negative number to loss of pollutant from the lake (i.e., volatilization). Thus, the resulting number expresses the mass of a pollutant going into or coming out of the lake per year (i.e., a positive net gas transfer indicates a net input of the pollutant to the lake and a negative net gas transfer indicates a net loss or output from the lake).
[c] Data from 1992 may represent an underestimation in the measurement of benzo(a)pyrene.

Sources: Eisenreich and Strachan 1992; Hillery et al. 1996; Hoff et al. 1996; and Strachan and Eisenreich 1988.

TABLE IV-2
Average Estimated Atmospheric Loadings[a] of Selected Pollutants
to the Great Lakes (kg/year) (1991-1993)

Atmospheric Process[b]	Lake Superior	Lake Michigan	Lake Huron	Lake Erie	Lake Ontario
PCBs					
Wet deposition	58	52	180	21	58
Dry deposition	27	16	---	16	5.7
Net gas transfer[c]	-1700	-2700	---	-420	-440
Absorption	320	390	---	340	130
Volatilization	-2000	-3100	---	-760	-560
Dieldrin					
Wet deposition	21	58	10	28	11
Dry deposition	7.4	8	---	5.6	1.7
Net gas transfer	-780	---	---	-610	-320
Absorption	120	200	---	67	43
Volatilization	-910	---	---	-680	-370
DDE					
Wet deposition	2.6	3.8	10	4.6	4.5
Dry deposition	0.4	0.5	---	0.5	0.2
Net gas transfer	---	---	---	---	-170
Absorption	10	26	---	14	12
Volatilization	---	---	---	---	-180
Lindane					
Wet deposition	62	65	140[d]	46	51
Dry deposition	0.6	1.1	---	0.4	0.2
Net gas transfer	140	1200	---	61	16
Absorption	340	1400	---	180	72
Volatilization	-200	-140	---	-110	-56
Benzo(a)pyrene					
Wet deposition	140	170	---	180	56
Dry deposition	58	77	---	63	60
Net gas transfer	87	---	---	---	---
Absorption	100	92	---	51	7.5
Volatilization	-17	---	---	---	---

[a] Values calculated from atmospheric loading equations, and based on atmospheric concentration data collected from Integrated Atmospheric Deposition Network (IADN); summarized from Hoff et al. (1996).
[b] Wet deposition based on estimated annual precipitation rates, and does not use actual rainfall amounts. Dry deposition represents only data for particle form of pollutant (i.e., gaseous form included in absorption values).
[c] Net gas transfer is the sum of gas absorption and volatilization. Water concentration data are taken from past literature and compared with the more recent air measurements, which may lead to some potential error in gas transfer estimates. Values for net gas transfer are rounded off and thus estimates may not add up in the table.
[d] High estimated value may be due to very limited number of samples for 1992 season and should be reconsidered as more data become available (Hoff et al. 1996).
--- Not determined or reported.

toxaphene, and mercury are given greater focus because fish advisories are currently issued for these pollutants. Fish advisories also exist for chlordane and dioxins for the Great Lakes, but they are not addressed in this section because recent information is limited. Potential sources of the pollutants are also discussed, as well as uncertainties in the data.

PAHs

Polycyclic aromatic hydrocarbons (PAHs), a subset of POM, are a class of semi-volatile compounds produced in combustion processes and are widely distributed in the environment. As indicated in the First Report to Congress, approximately 72 to 96 percent of the total annual loading of one common PAH, benzo(a)pyrene, to Lakes Superior, Michigan, and Huron is attributed to atmospheric deposition.

PAHs are detected both in the gaseous and particulate phases, but some of the most toxic PAHs are largely in the particulate phase in the atmosphere. For the most toxic PAHs, dry deposition is generally the main route of deposition to the lakes (Hoff and Brice 1994). For benzo(a)pyrene, however, wet deposition seems to be the major source of atmospheric loadings to Lake Michigan in all seasons of the year. The IADN data suggest that, for Lake Superior, the net movement of the gaseous phase benzo(a)pyrene is largely to the water; data are limited for the other lakes (see Table IV-2). Comparing recent wet and dry deposition values with historic data, the loading of benzo(a)pyrene to the lakes appears to have increased (Table IV-1). However, the 1992 finding may be attributed to an underestimation in the measurement of benzo(a)pyrene (Hoff et al. 1996).

A recent study found that total wet and dry deposition for benzo(a)pyrene was 50 times higher at an urban site (Chicago) than at remote IADN sites in Lakes Michigan and Superior (Sweet and Harlin 1996). The investigators concluded that large areas of Lake Erie, Lake Ontario, and southern Lake Michigan have elevated PAH deposition rates due to emissions from nearby urban areas. Although the total deposition of PAHs are lower in rural than urban sites, the relative amounts of the individual PAHs (i.e., relative ratios of the individual PAHs) is very similar at urban and nonurban sites, suggesting that little chemical degradation occurs during transport of PAHs from urban source areas to rural and remote sites several hundred kilometers away.

PCBs

PCBs are a class of highly toxic, persistent, and bioaccumulative chemical compounds. PCBs in Great Lakes fish have long been linked to developmental and growth problems in infants born to women who regularly consumed PCB-contaminated fish in the late 1970s. PCBs were produced from 1927 to 1977 for the purpose of insulating and cooling electrical equipment. In the late 1970s, Monsanto Company, sole manufacturer of PCBs in the United States, voluntarily stopped production of PCBs. Estimates suggest that 282 million pounds of pure PCBs -- 20 percent of PCBs ever produced -- were still in service at the end of 1988.

PCBs manufactured before production was stopped are still found in the Great Lakes. They are present in older commercial and industrial equipment (e.g., transformers, capacitors). There are no phaseout deadlines that require removal of the equipment to avoid breakage and release, although this equipment is tightly regulated under the Toxic Substances Control Act (TSCA). As a result of past use and disposal practices, PCBs may reside in sediments in surface waters and in other areas, such as waste sites. As the contaminated sediment is disturbed, the

PCBs may be re-released and resuspended in the water, allowing for continued bioaccumulation in Great Lakes fish. Remediation programs are in-place to address PCB-contaminated waste sites. Other continuing PCB sources include unregulated sources that potentially contain PCBs and releases, as well as releases by those PCB owners who are not aware of the presence of PCBs or of the special management requirements for PCB-containing equipment.

Despite the fact that PCBs are one of the most tightly regulated and controlled group of pollutants under federal regulatory programs, fish consumption advisories still exist for PCBs in all five of the Great Lakes (see Appendix B). For example, although PCB levels have declined in Lake Michigan water, there has been a constant or increasing level of PCBs in some Lake Michigan fish in the last few years, possibly due to resuspension from sediment or from changes in the Lake Michigan food chain (see Section II.B).
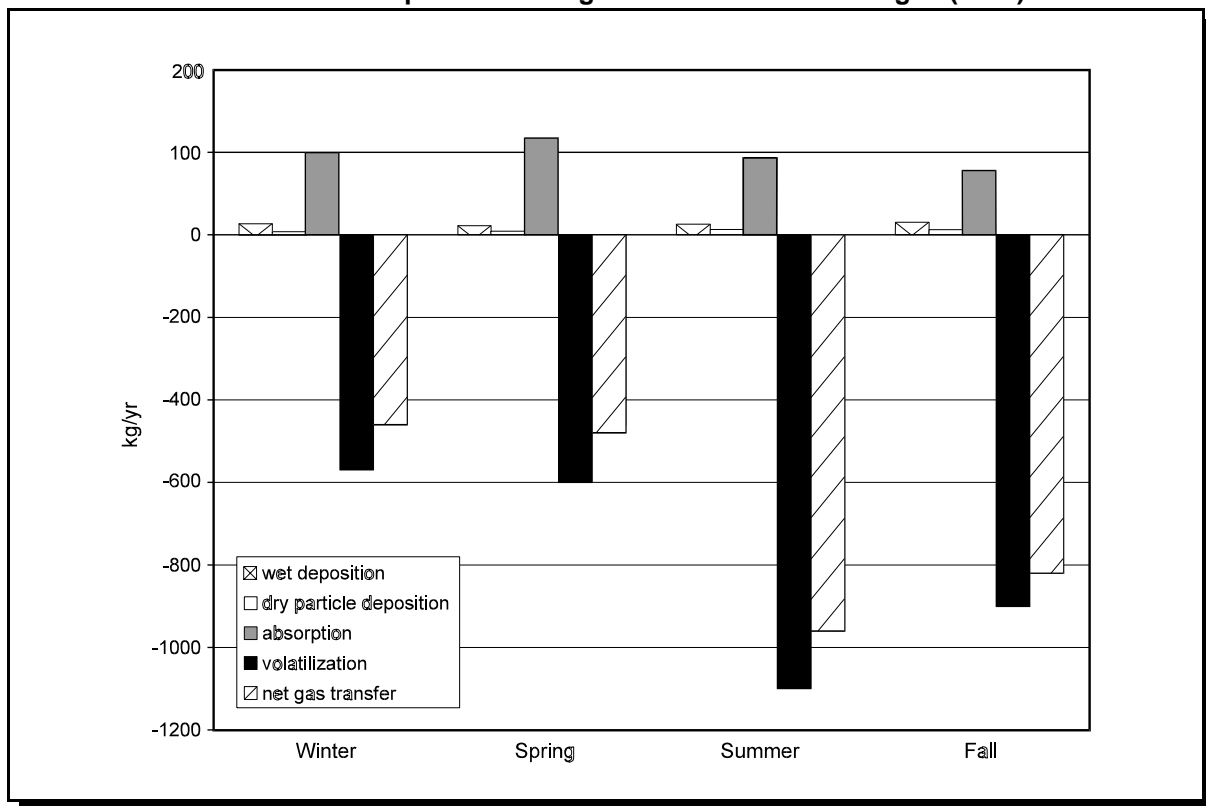
Volatilization is the dominant mechanism in air-water gas exchange of PCBs (Table IV-2). Volatilization of PCBs from the Great Lakes is estimated to be as high as 3,100 kg/year for Lake Michigan and 2,000 kg/year for Lake Superior. In contrast, estimates of wet deposition of PCBs are less than those for volatilization and are nearly the same for Lakes Superior, Michigan, and Ontario (52-58 kg/year) with Lake Erie showing a lower rate (21 kg/year) and Lake Huron showing the highest rate (180 kg/year) (Table IV-2). Dry deposition rates of PCBs are similar in Lakes Superior, Michigan, and Erie (16-27 kg/year), with Lake Ontario showing a lower rate (5.7 kg/year). As presented in Table IV-1, from 1988 to 1994, wet and dry deposition of PCBs to each of the Great Lakes has decreased. Therefore, the net loss to the atmosphere would suggest that the amount of PCBs in water is declining. Tables IV-1 and IV-2, however, represent data only for the atmospheric movement of pollutants and therefore, do not indicate the waterborne inputs to each lake (such as particles in the water, industrial water discharges, and especially urban storm-runoff which goes directly into the lakes). Also, this study on gas exchange is preliminary and there are considerable uncertainties in the estimates. Additional work addressing the uncertainties and other routes of pollutant movement may give a different balance, although the importance of gas exchange is clear.

Wet and dry deposition of PCBs are similar over seasons, while net gas exchange is highly seasonal, exhibiting much greater effect with high temperatures (Figure IV-3). To date, no studies on seasonal variation in PCB concentrations in water have been published to compare with the seasonal atmospheric loading data. As stated earlier, uncertainties exist in calculating deposition estimates, since some estimates are based on rough approximations or assumptions using the best science available at this time.

PESTICIDES

Volatilization of the pesticides dieldrin and DDE (a metabolite of DDT) in many of the Great Lakes is a significant process. Net atmospheric loading is negative, indicating that movement of these two pesticides between air and water is mostly volatilization (Table IV-2). Fluctuations in gas equilibrium conditions may be influenced by the water concentration data, differences in temperature, and/or errors in the Henry's Law constant used in calculating gas movement. For example, DDT net gas transfer estimates are hindered by difficulties in obtaining precise water concentration data because DDT levels in the lakes are close to the analytical detection limit. From Table IV-1, DDT wet and dry deposition loadings declined between 1988 and 1992, but rose slightly for all lakes except Lake Superior in 1994 (Hillery et al. 1996).

FIGURE IV-3
Seasonal Atmospheric Loadings of PCBs in Lake Michigan (1994)

Wet and dry deposition of lindane appeared to be fairly uniform across all lakes (see Table IV-2). Gaseous lindane generally seemed to be in equilibrium within Lakes Erie and Ontario, while gas absorption is the dominant mechanism in air-water exchange for Lakes Superior and Michigan (Table IV-2). The net gas transfer of lindane in Lake Michigan is into the lake in the winter and spring and out of the lake in the summer and fall. For many pesticides, gas transfer is strongly dependent on seasons, with net outputs in the summer and net inputs in the winter (Achman et al. 1992; Hoff et al. 1993; McConnell et al. 1992; Ridal et al. 1996).

Toxaphene in the Great Lakes Basin. Toxaphene, a semi-volatile insecticide containing a mixture of chlorinated bornanes (class of aromatic hydrocarbons), has been recognized as one of the contaminants with the highest concentrations in Great Lakes fish (Ribick et al. 1982; Schmitt et al. 1981, 1985, 1990). Because of its volatility and persistence, toxaphene is still widely distributed through the atmosphere, even though it is no longer used in the United States (Rapaport and Eisenreich 1986). Toxaphene was been found to be a major contaminant in lake trout and whitefish from Siskiwit Lake on Isle Royale, Lake Superior (De Vault et al. 1996) (see sidebar).

> **Toxaphene in Lake Trout**
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> Since 1991, the state of Michigan has issued a consumption advisory for Siskiwit lake trout from Lake Superior based on exceedance of the FDA's 5.0 ppm action level for toxaphene. In 1995, the Canadian Province of Ontario issued fish consumption advisories for several different species in Lake Superior and upper Lake Huron, triggered by their toxaphene levels and a lowering of Health Canada's action level for toxaphene to 0.2 ppm.

Toxaphene's discovery on pristine Isle Royale, exposed only to atmospheric deposition, seemed indicative of long-range transport via the atmosphere since it had been used primarily as a pesticide in the southern United States (Hoff et al. 1993). This hypothesis has been supported by studies that found toxaphene concentrations in Canadian air masses that had originated in the southern United States. However, there is also evidence to suggest that some of the toxaphene found in Lake Superior and northern Lake Michigan may have local origins. A study that analyzed fish from rivers in the southeastern United States, the Great Lakes, and Isle Royale, collected during 1982, found differences in composition of toxaphene in fish between sites, suggesting that potential local influence may be important, rather than long-distance atmospheric transport from the southeastern United States to the Great Lakes (Petty et al. 1987).

EPA recently supported monitoring of toxaphene in Great Lakes fish and sediment which has revealed two trends. First, there has been a statistically significant decline in the concentration of toxaphene in fish from most waters, as might be expected following reduced use and later cancellation of the pesticide. Second, there has been no discernible decline in toxaphene levels in Lake Superior lake trout; toxaphene levels are higher than levels of other measured contaminants in fish from anywhere in the Great Lakes.

At this time, there are several hypotheses for the relatively elevated levels of toxaphene observed in Lake Superior and northern Lake Michigan. First, the continued use of toxaphene by other countries and subsequent atmospheric transport to the Great Lakes basin may increase levels. Another possibility is the previous local use of the pesticide. Toxaphene was once used to kill undesirable fish communities (Lockhart et al. 1992; Stern et al. 1993). This practice occurred in parts of Canada and the northern United States for fish restocking on small glacial lakes; it was applied to at least 80 lakes during the 1950s and 1960s in Wisconsin (Hughes 1968). It has also been proposed that Lake Superior lake trout may be slower to reflect a decrease in contaminant levels in their food web due to their greater age; however, Glassmeyer et al. (1997) found that toxaphene levels in Lake Superior fish were still elevated compared to levels in fish from the other lakes. Another explanation that has been suggested is that toxaphene persists longer in colder, less productive waters such as Lake Superior. Finally, the high toxaphene levels may be a result of the release of toxaphene into the waters as a byproduct in the production of paper; there are 74 pulp and paper mills that directly discharge to all the Great Lakes (IJC 1995), with the paper industry most concentrated near Lake Superior and upper Lake Michigan (Green Bay).

TRACE METALS

A number of trace metals are of concern in the Great Lakes, though new data are limited. Data from 1994 suggest that wet deposition is the dominant atmospheric transport mechanism for trace metals to the Great Lakes (Hoff and Brice 1994). The most consistent trend in the deposition of trace metals was the reduction in lead in 1994 compared with 1988 values for all the lakes (Figure IV-4). This finding is not surprising given the phaseout of leaded gasoline in the United States beginning in the 1970s and accelerating in the mid-1980s. The gaseous phase of lead is assumed now to be negligible. Arsenic deposition also has decreased. The reason for this finding is not as clear but it has been hypothesized that process changes by Noranda, a major emitter of arsenic in Canada through mining, smelting, and refining of metal products, may have led to the decline.

FIGURE IV-4
Atmospheric Loadings of Lead to the Great Lakes (1988-1994)
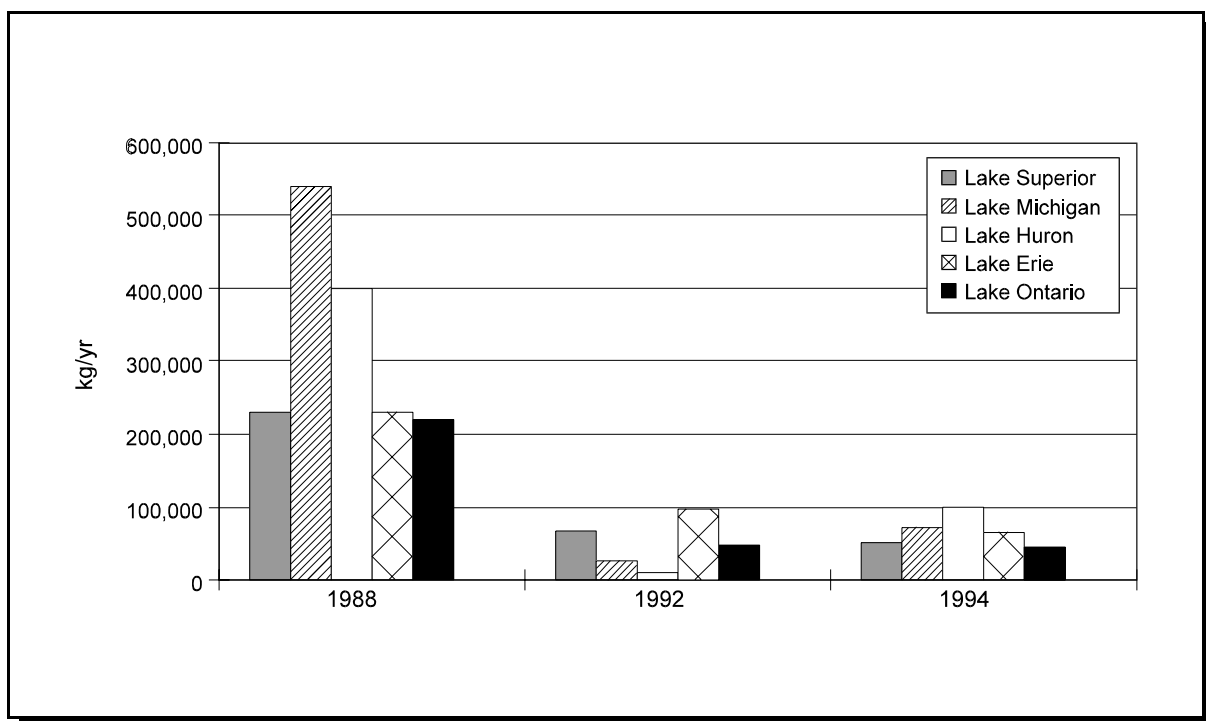
Mercury in the Great Lakes Basin. Currently, six of the eight Great Lakes states (Michigan, Ohio, Wisconsin, New York, Pennsylvania, and Minnesota) have issued advisories restricting consumption of fish from some state waters due to mercury contamination. Mercury contamination, or high mercury levels in fish tissue, is also the most frequent basis for fish advisories issued by the Province of Ontario. Many of their advisories are applicable to areas of the Great Lakes.

During the early 1970s, mercury was found in fish from Lake Huron, Lake St. Clair, western Lake Erie, eastern Lake Ontario, and the St. Lawrence River at levels that led the United States and Canada to close commercial fisheries. Subsequently, mercury levels fell in these waters, because of modification or closure of certain chloralkali facilities and pulp and paper mills whose wastewater discharges contained large quantities of mercury. In 1970, mercury levels in Lake St. Clair walleye were 2 parts per million (ppm); by the mid-1980s, levels in these walleye had subsided to 0.5 ppm (Environment Canada et al. 1991). There are other signs of reduced mercury levels in the Great Lakes through dated sediment cores and populations of smelt in the lakes.

Because of large direct discharges of mercury being terminated following implementation of the Clean Water Act (CWA), the atmosphere is now the dominant pathway by which mercury reaches the Great Lakes. Currently, the best estimate of atmospheric deposition to the five Great Lakes is approximately 6,800 kg per year (15,000 pounds) (Eisenreich and Strachan 1992). Loadings of mercury to Lakes Superior and Michigan are primarily from the atmosphere. For Lake Ontario, the percentage of atmospheric contribution of mercury is relatively modest because the lake receives mercury from waters that flow from the upper lakes (Sitarz et al. 1993).

Even some of the mercury borne to the Great Lakes via their tributaries includes contamination previously deposited from the atmosphere to their watersheds.

Unlike other trace metals, mercury exists in the air predominantly in the gaseous phase due to its volatility. Estimates of wet and dry deposition of mercury to Lake Superior are about five times higher than net gas transfer to the atmosphere. The net annual atmospheric loading of mercury to Lake Superior is calculated to be about 635 kg/year (Hoff et al. 1996), which is comprised of the following estimates:

- 560 kg/year as wet deposition;
- 250 kg/year as dry deposition;
- 65 kg/year as absorption; and
- -240 kg/year as volatilization.

In an earlier study, gaseous phase mercury in the atmosphere was 1.57 ng/m^3, particulate phase mercury, 0.02 ng/m^3, and precipitation mercury, 10.5 ng/L, at a northern Wisconsin site near Lake Michigan (Fitzgerald et al. 1991). Comparison of these values with other U.S. sites is presented in Table IV-5 in Section IV.B.

In Michigan, atmospheric concentrations and wet deposition of mercury have been observed to vary geographically. Northern Michigan received only one-half the wet deposition of mercury deposited to southern portions of the state. Wet deposition varied by season, with mercury concentrations in precipitation two times greater during spring and summer than during winter. Higher levels of particulate mercury were observed in large urban areas. Modeling indicated that the dominant sources of mercury were located mostly to the south and west of Michigan (Keeler and Hoyer 1997).

Program Actions to Characterize Atmospheric Contamination in the Great Lakes

Research has occurred in the past few years to increase understanding of the effects, fate, and transport of toxic substances in the Great Lakes ecosystem. These efforts are designed to provide information to further characterize, as well as reduce, atmospheric contamination in the Great Lakes region. Some of the programs to assess the extent of atmospheric contamination in the Great Lakes basin are described below. At this time, many of these projects are collecting and/or compiling data, and results are not yet available for evaluation. Also, several notable programs/activities have been introduced in recent years to begin to reduce loadings and to mitigate existing contamination and are discussed in the following section (Toxics Reduction Efforts in the Great Lakes).

LAKE MICHIGAN MONITORING PROGRAM

A monitoring program for Lake Michigan has been implemented by EPA's Great Lakes National Program Office to support a number of activities that address reductions in the release of toxic substances, particularly persistent, bioaccumulative substances, to the Great Lakes system. The program is a key element of the Lakewide Management Plan (LaMP) for Lake Michigan (see next subsection, Toxics Reduction Efforts in the Great Lakes, for general information about the objectives of LaMPs).

The water quality criteria and values provided in the GLWQ Guidance, once adopted by the Great Lakes states, would apply to the entire Great Lakes system, regardless of the source of pollutants to those waters. In this manner, the proposed water quality criteria and the measured values provide the basis for integrating actions carried out under the range of environmental programs available to federal, state, and tribal agencies to protect and restore the Great Lakes ecosystem. The mass balance approach will facilitate this integration by evaluating multi-media load reduction actions required to ensure that Lake Michigan water quality meets the Great Lakes water quality criteria (GLWQC).

The primary goal of the Lake Michigan Monitoring Program is to develop a sound, scientific base of information to guide future toxic load reduction efforts at federal, state, tribal, and local levels. In particular, the following specific objectives are identified:

- Evaluate relative loading rates of critical pollutants by medium (atmospheric deposition, contaminated sediments, tributaries) to establish a baseline loading estimate to gauge future progress;

- Develop the predictive ability to determine the environmental benefits of specific load reduction scenarios for toxic substances and the time required to realize those benefits, including evaluation of benefits of existing environmental statutes and regulations; and

- Improve our understanding of the key environmental processes that govern the cycling and bioavailability of contaminants within relatively closed ecosystems.

Lake Michigan Mass Balance Study. One of the ways to address the objectives of the Lake Michigan Monitoring Program, as well as to assist EPA in implementing section 112(m) of the CAA, is through a mass balance study. The mass balance study will characterize the loadings, transport, and fate of selected pollutants in a defined ecosystem, through monitoring and modeling. These measuring and estimating techniques can be applied to other ecosystems. EPA initiated the Lake Michigan Mass Balance Study, a comprehensive sampling effort that includes measurements of contaminants in the atmosphere, tributaries, lakewater, sediments, and food chain, to support model components. The atmospheric sampling sites for this mass balance study are shown in Figure IV-5.

> **Application of Modeling Tools from the Green Bay Mass Balance Study**
>
> In a pilot mass balance study by EPA and the Wisconsin Department of Natural Resources, water-insoluble organic compounds were monitored in Green Bay, Wisconsin, from 1988 to 1992. The analytical and modeling tools used in the study may be applied to the Great Lakes, Lake Champlain, and coastal estuaries. The **Lake Michigan Mass Balance study** is the first full-scale application of this methodology for toxic pollutants and will serve as the basis of any future mass balance efforts for persistent, bioaccumulative chemicals. Data collected for this study are anticipated in 1997.

The Lake Michigan Mass Balance model is constructed for a limited group of pollutants (PCBs, trans-nonachlor [a bioaccumulative component of chlordane], and total mercury) present in Lake Michigan at concentrations that pose a risk to aquatic and terrestrial organisms (including humans) within the ecosystem, or that may accumulate to problematic concentrations

FIGURE IV-5
Atmospheric Monitoring Sites in the Great Lakes Region
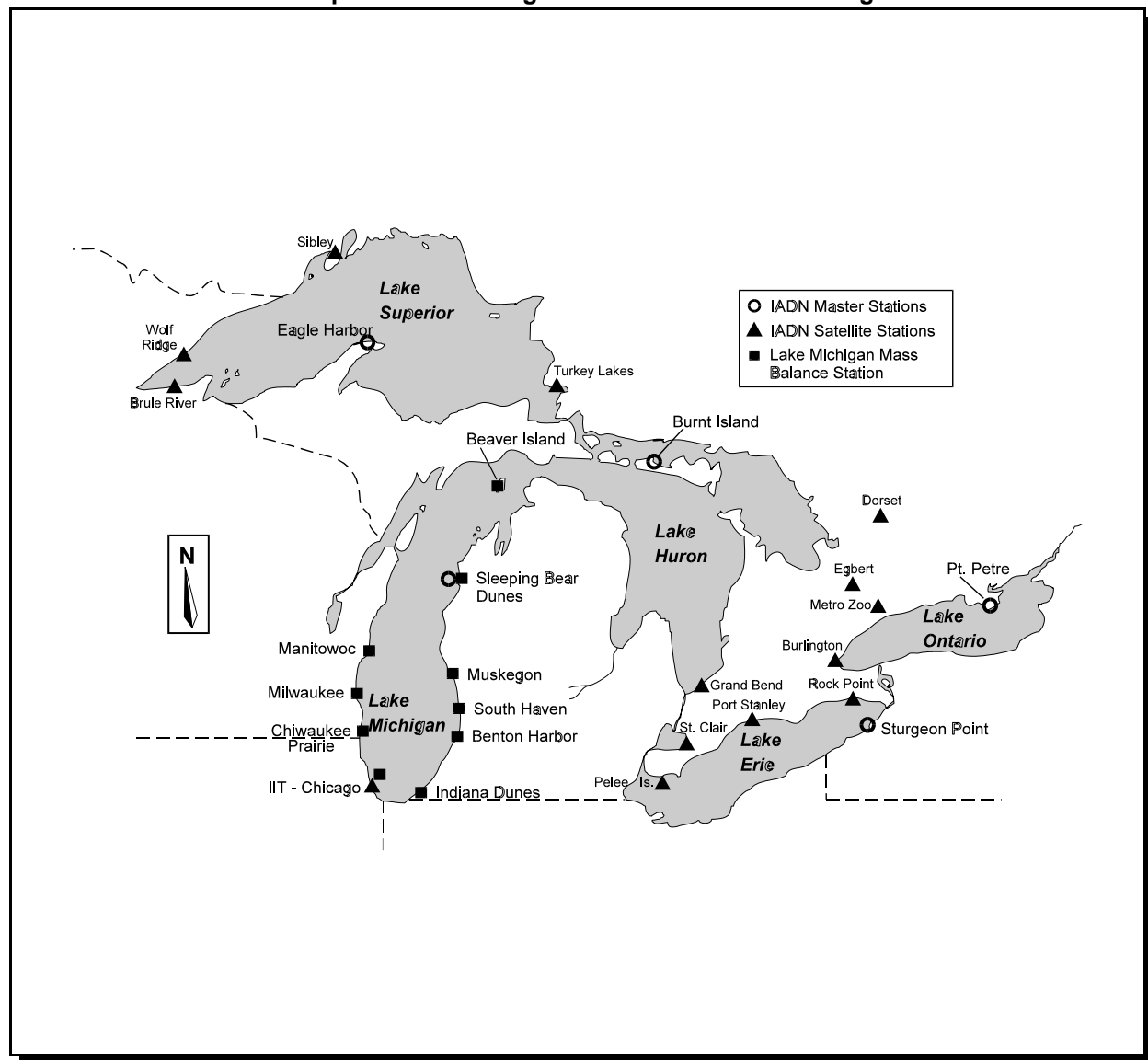
in the future and that can serve as examples for other chemicals. In addition, atrazine (under consideration for addition as a Great Waters pollutant of concern), a commonly used herbicide in the Great Lakes basin and elsewhere in the United States, is also included in the model. This herbicide has been reported at elevated concentrations in Lake Erie tributaries, in the open waters of the Great Lakes, and in the atmosphere over the lakes. The inclusion of this chemical will provide a model for the more reactive, biodegradable compounds in current use. The model will be less comprehensive than that for PCBs and trans-nonachlor, because atrazine does not appreciably bioaccumulate and it will not be analyzed in the food chain.

The chemicals chosen cover a wide range of chemical and physical properties and are representative of other classes of compounds that could pose water quality problems. This approach will allow modeling of many other chemicals with limited data. Resource limitations, quality assurance requirements, and analytical and data handling limitations preclude intensive

monitoring and model calibration for more than the above described target chemicals. While mass balance modeling will focus on the above chemicals, the determination of loadings and concentrations for additional contaminants and compounds useful for source apportionment and deposition modeling will be undertaken as part of the Lake Michigan Monitoring Program.

The Lake Michigan Mass Balance Study includes an atmospheric monitoring component to address research issues concerning urban and atmospheric deposition and exchange processes. The data will be used to calculate atmospheric loads to the ecosystem. Within this air transport component, special studies are being performed to determine whether emissions of hazardous air pollutants from the urban coastal regions (Chicago, IL, and Gary, IN) contribute significantly to atmospheric deposition to the adjacent waterbodies. The objectives of these special studies are to (1) measure wet and dry deposition fluxes of urban contaminants, (2) determine contributions of urban source categories to measured concentrations and deposition rates, and (3) assess the extent of air-water exchange of contaminants.

Previous studies indicated that urban emissions have a large impact on atmospheric concentrations of air toxics and on atmospheric deposition to the Great Lakes. Dry depositional flux of PCBs from Chicago was shown previously to be three orders of magnitude higher than that of non-urban areas (Holsen et al. 1991). In addition, the Lake Michigan Urban Air Toxics Study demonstrated that concentrations of several pollutants were significantly higher in Chicago urban areas than at less urbanized sites (Keeler 1994). An intensive study was recently conducted around Chicago to assess the impact of the urban area on atmospheric deposition and exchange with Lake Michigan, with three land-based monitoring sites around Chicago and one over-water site on a research vessel approximately five miles off the shore of Chicago. The three sampling periods that occurred between 1994 and 1995 were designed to provide information to track atmospheric plumes over and across the lake. Wet deposition, dry deposition, and lake water were analyzed for semi-volatile compounds (such as PCBs and PAHs) and trace metals (such as arsenic, mercury, and lead). All samples were taken on the same day to provide information on air-water exchange of contaminants. Results from this study are expected in 1997, with modeling results expected in 1998. This study is expected to contribute useful information on urban impact to Lake Michigan, as well as to address process-oriented research issues and provide data in support of source apportionment and trajectory modeling.

INTEGRATED ATMOSPHERIC DEPOSITION NETWORK (IADN)

As mentioned earlier in this chapter, IADN is a long-term, binational program between the United States and Canada to assess the magnitude and trends of atmospheric deposition of target chemicals to the Great Lakes and to determine emission sources wherever possible. The program addresses the mandate of the Great Waters program and the needs of Annex 15 of the GLWQA between Canada and the United States. It is designed to (1) provide the necessary standardized methods, monitoring data, and loadings estimates to assess the relative importance of atmospheric deposition compared to other inputs, (2) determine temporal trends and geographic variations in deposition, and (3) ultimately provide information on sources of these atmospheric pollutants. It is a combination of a surveillance/ monitoring network and a research program. Its goals are source attribution, process identification, and assessment of atmospheric impacts on environmental systems. At this time, annual and seasonal averages have been completed for four years of IADN operation. Data for selected pollutants were presented earlier

in this section. Additional details may be found in Eisenreich and Strachan (1992), Gatz et al. (1994), and Hoff et al. (1996).

Target compounds were chosen for IADN based on their potential to bioaccumulate, their tendency to be transported atmospherically, and the availability and efficiency of detection methods (see sidebar). A major benefit of IADN is the ability to monitor long-term atmospheric concentration changes of such compounds as PCBs and other chemicals of concern. In the past, such regional-scale atmospheric data have been sparse.

It was originally projected that, to be representative of regional deposition patterns, the IADN required one "master" station and several "satellite" stations on each lake. The master stations are: Eagle Harbor, MI; Sleeping Bear Dunes, MI; Burnt Island, Ontario; Sturgeon Point, NY; and Pt. Petre, Ontario (see Figure IV-5). Several satellite sites were later added, including an urban site in Chicago (see box on next page). The IADN implementation design allows for periodic evaluation of the existing sites to determine whether other sites are needed.

At each IADN site, concentrations of target chemicals are measured in rain and snow (wet deposition), airborne particles (dry deposition), and airborne organic vapors. In addition, precipitation rate, temperature, relative humidity, wind speed and direction, and solar radiation are measured at each site. IADN results for selected pollutants are presented in Tables IV-1 and IV-2.

At this time, after five years of operation, many of the sampling and analysis issues of IADN have been resolved. For example, comparability of sampling and analytical procedures between jurisdictions was achieved through extensive laboratory intercomparison studies. However, the uncertainty in the analytical measurement of some compounds is still above the uncertainty threshold acceptable to most policy makers. Toxic chemicals at extremely low concentrations in air, such as PCBs and some agricultural chemicals, have the highest uncertainties in sampling (over 40 percent). Relative standard deviations of air concentrations of organochlorinated compounds may vary from 60 to 90 percent, due to seasonal and annual fluctuations in the air, rather than precision of the measurement (Hoff et al. 1996).

Uncertainty in the deposition estimates may result from various factors: (1) general approximations for estimating deposition; (2) climatic and meteorological variations; (3) differences in the instrumentation and the scope and objectives of the various jurisdictions and agencies involved; and (4) estimation of factors used to calculate loadings (e.g., magnitude of Henry's Law constants, rates of contaminant transfer between the air and water). Despite these

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Compounds Measured in IADN

- **Highest priority group:** PCBs, lindane, PAHs, and lead. These pollutants were chosen for the first phase of IADN (1990-1992) to demonstrate the feasibility and accuracy of sampling and analytical methods.

- **Second priority group:** Chlorinated pesticides (such as HCB, DDT/DDE/DDD, trans-nonachlor, methoxychlor, mirex, dieldrin, aldrin) and trace metals (such as arsenic, selenium, cadmium, and mercury). Except for mercury, the sampling and analysis methods for most of these species had been implemented by 1993. Mercury monitoring was added at each IADN site by 1995.

- **Third priority group:** Compounds such as toxaphene, dioxins/furans, and agrochemicals which have an important atmospheric component but require additional methods development to accurately measure their concentrations in atmospheric deposition samples.

Urban Influence on Atmospheric Deposition of Contaminants

The primary focus of IADN is to determine regionally representative atmospheric deposition loadings of toxic chemicals to the Great Lakes. Thus, monitoring stations were positioned to minimize the influence of local sources and to monitor the atmospheric environment over the lakes as much as possible. This approach does not directly enable the determination of the role of urban air pollution. Recent research suggests that deposition of contaminated large particles carried by winds passing over urban areas can result in substantial inputs of toxic chemicals to the Great Lakes (Falconer et al. 1995; Holsen et al. 1991).

The influence of pollution from the Chicago-northwest Indiana area on water quality in southern Lake Michigan was studied by Sweet and Basu (1994). The Sleeping Bear Dunes site (in the State of Michigan) is located one kilometer from the northeastern shore of Lake Michigan and 50 kilometers from the nearest urban area or major source and, thus, is considered a "remote" site. The first urban site is located 1.5 kilometers from the shore on the campus of the Illinois Institute of Technology, which is near major expressways and surrounded by commercial and residential areas. The second urban site is located at the Indiana Dunes National Lakeshore in the vicinity of large steel mills. Particulate concentrations were measured for target compounds (PCBs, pesticides, and trace metals). Gas concentrations of PCBs and pesticides were determined, and rain was analyzed only for PCBs.

Results from Sweet and Basu (1994) indicate that, for PCBs, DDT (and its metabolites), dieldrin, chlordane, and several trace metals (manganese, zinc, chromium, and lead), the measured particulate and gas concentration values were 10 to 40 times higher in urban areas than at the remote site. For other pesticides (α-HCH, lindane, HCB) and trace metals (arsenic and selenium), concentrations were nearly the same at all three sites, indicating these pollutants were well mixed in the air throughout the region (and that there were probably few local sources).

Though 90 to 99 percent of the PCBs were found in the gas phase, the most toxic PCB congeners were enriched in the particulate phase (Falconer et al. 1995; Holsen et al. 1991; Sweet and Basu 1994). Thus, dry deposition may be an important transport mechanism for certain, especially toxic, PCBs to the lakes. Urban particulate matter also carried high concentrations of trace metals and pesticides, causing dry deposition of these materials to southern Lake Michigan. Dry deposition of large particles may be especially significant for Lake Michigan because 200 kilometers of the southwest shoreline are heavily developed. Prevailing southwest winds carry emissions over the lake where they travel for 100 to 150 kilometers before reaching land again, allowing a significant portion of the deposition to enter the lake. Finally, the concentration of PCBs in precipitation is roughly the same in urban and rural sites. The relatively low levels found in urban precipitation may be due to the fact that many contaminants are collected in clouds or by rain upwind of polluted areas.

Clearly the influence of urban areas on atmospheric deposition of certain pollutants to the Great Lakes is substantial, especially in heavily developed areas, such as the southwestern shores of Lake Michigan.

limitations, the reported estimates are the best that are currently available. Also, data on the concentration of contaminants in the water column for all the Great Lakes have improved recently with more samples being collected and analyzed.

GREAT LAKES EMISSIONS INVENTORIES

A significant step toward assessing the need to reduce atmospheric loads of hazardous air pollutants to the Great Lakes is to identify, categorize, and estimate the magnitude of the pollutant sources. By creating an emissions inventory data base, it is possible to identify the sources and source categories that contribute most to the total emissions in a given geographic area, as well as to model emissions transport and deposition. An air emissions inventory is typically based on mathematical estimates of pollutant releases through the use of emission

factors (e.g., a number that represents emissions per unit burned, produced, or processed). These emission factors are derived from actual measurements of the emissions from representative sources and are derived specifically for one type of process or process equipment. Emission factors can be used, for example, to estimate both the amount and type of pollutants being emitted from an air pollution source based upon the quantities of material processed.

The 1986 Great Lakes Governors' Toxic Substances Control Agreement specified provisions to address atmospheric deposition, including a commitment "to cooperate in quantifying the loadings of toxic substances originating from all sources, with the purpose of developing the most environmentally and economically sound control programs." In response to the governors' direction, the air regulatory agencies in the eight Great Lakes states and the province of Ontario began to work cooperatively in 1987 to investigate "the development of a computerized air toxics data base for the purpose of obtaining a better understanding of the nature and sources of toxic air emissions and their migration, dispersion, and resulting impact upon the Great Lakes basin." Under the auspices and management of the Great Lakes Commission (representing the eight Great Lakes states) and with major funding from EPA's Great Waters program, the Great Lakes states began developing a *regional* air toxics emissions inventory. This first regional inventory is scheduled for completion in 1997 and is expected to compile 1993 emissions data for 49 toxic air pollutants from point and area sources. Emissions data on toxic air pollutants from mobile sources will be developed in 1997-1998. These 49 pollutants include 10 of the Great Waters pollutants of concern (cadmium, chlordane, hexachlorobenzene, lead/alkylated lead, mercury, PCBs, PAHs, POMs, TCDD, TCDF). The continued partnership of the region's air regulatory agencies, now in its eighth year, and the high level of regional cooperation and coordination exemplifies the commitment to decreasing toxic deposition into the Great Lakes ecosystem. Yet the inventory must be accompanied by an ongoing commitment to further quantify, assess, and report on the effects of voluntary and regulatory reductions of air toxics emissions.

The key to the state's coordinated efforts is *The Air Toxics Emissions Inventory Protocol for the Great Lakes States*, developed in June 1994 (see sidebar). The Protocol will be followed by each participating state ensuring that consistent, agreed-upon best methodologies are used among all states when compiling a quality-assured inventory. This Protocol is an evolving document and will be updated or revised as needed and agreed upon by all the Great Lakes states.

The second fundamental component in developing a toxic air emissions inventory is the Regional Air Pollutant Inventory Development System (RAPIDS), a multi-state pollutant emissions estimation and storage software system. RAPIDS is a state-of-the-art, networked, relational data management and emission estimation

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Components of Great Lakes Emissions Inventory

To date, the Great Lakes States have developed and tested two fundamental components of the inventory effort:

1. **The Air Toxics Emissions Inventory Protocol for the Great Lakes** - A guide for each state's efforts to identify sources and estimate emissions so that the inventory is complete, accurate, and consistent from state to state.

2. **RAPIDS** - A client/server relational database software and data management and emissions estimation system. It was designed so that the Great Lakes states may adopt RAPIDS (or some variant of it) for their state system, and may also submit their data for incorporation with the regional RAPIDS data base at EPA.

system, bridging each state's individual inventory and computer system to the regional RAPIDS repository of inventory data. RAPIDS' strength is its versatility. States can modify or build upon it to serve their particular needs. It can be used to estimate both toxic and criteria pollutant emissions from a single device within a facility or a complex grouping of devices and controls, or even across geographic areas, ranging in size from one facility to the entire Great Lakes region. It is designed to run on a personal computer and applies a flexible data model that can be easily expanded in the future to support multi-media, permitting, monitoring, reporting, and compliance activities in the states. Emission factors are uploaded from EPA's Factor Information Retrieval System (FIRE), which contains quality-rated emission factors for both criteria and hazardous air pollutants.

Using RAPIDS, the Great Lakes states' air regulatory agencies are building a comprehensive, updatable statewide and regional air toxics inventory for point, area, and (in the future) mobile sources for the 49 air pollutants. Each of the eight Great Lakes states will be responsible for compiling, uploading, and validating their state emissions inventory data. It is anticipated that the inventories will be updated on a one- or two-year basis.

Four states (Illinois, Indiana, Wisconsin, and Michigan) completed a pilot study of major urban areas along the southwest shore of Lake Michigan in December 1995 using RAPIDS and the Protocol. The states created an inventory of small point and area source categories in the 12 shoreline counties encompassing Chicago (Illinois), Gary (Indiana), and Milwaukee (Wisconsin) that contribute the most to the total emissions of the 49 pollutants of concern. These area sources include gasoline stations, foundries, asphalt and cement plants, and hospitals, among others. The project was the first rigorous test of the regional Protocol and the RAPIDS software. Total pollutant emissions from the inventoried sources were collected, but data interpretations and conclusions were not developed from the results. Instead, the process of compiling the regional inventory was used as a means of resolving many technical, methodological, and policy-related issues that impact a multistate, regional toxic air emissions inventory. Furthermore, the pilot study provided useful information on serious shortcomings that still exist in the regional emissions estimates and suggested necessary steps that must be made to ensure data quality for estimating various pollutant groups. The results from this pilot study will also contribute for better methodology for use in the full eight-state regional inventory.

The level of emissions resolution and the source categories contained in RAPIDS were planned to meet the modeling needs of Great Lakes air quality researchers. This inventory will be available for dispersion and deposition models to characterize source, source category, and geographic contributions, and for mass balance models to characterize media contributions.

Toxics Reduction Efforts in the Great Lakes

In recent years, several programs/activities have developed approaches to reduce loadings and to mitigate existing contamination. These programs are described below. They may provide information to further characterize and reduce atmospheric contamination in the Great Lakes region.

VIRTUAL ELIMINATION

The Great Lakes Water Quality Agreement of 1978 between the United States and Canada called for the "virtual elimination" of persistent toxic substances, especially those which bioaccumulate, from the Great Lakes basin. In keeping with the obligations of the Great Lakes Water Quality Agreement, two major efforts have occurred: (1) a pilot project sponsored by EPA to develop the framework to achieve virtual elimination of two pollutants, mercury and PCBs; and (2) development of the Great Lakes Binational Toxics Strategy (released in April 1997) between the United States and Canada to set goals to reduce the use and release of selected pollutants. Many of the recommendations from the pilot project were incorporated into the Binational Toxics Strategy.

Virtual Elimination Pilot Project. Since 1990, both the United States and Canada have initiated separate efforts for virtual elimination. EPA began the Virtual Elimination Pilot Project in 1993, which was designed to answer the following question: "What options exist for improving the current regulatory and non-regulatory framework to encourage continuing reductions towards zero in the use, generation, and release of selected toxic substances?" The aim of the project was to identify barriers to achieving virtual elimination and to develop strategies to overcome these barriers.

The first iteration or "pilot" portion of the U.S. project focused on the reduction opportunities for two substances, mercury and PCBs. EPA held a meeting with stakeholders in the Great Lakes region in 1993 to share information on mercury and PCBs, and to offer participants the opportunity to make recommendations on ways to reduce the use and release of each pollutant. Based on the results of this meeting, a draft report was developed by EPA to identify options to reduce mercury (GLNPO 1995). A draft options paper for the virtual elimination of PCBs is currently being prepared by EPA. It is expected that this project will continue with the analyses of classes of substances rather than the use of a chemical-by-chemical approach.

Mercury presents an unusual challenge to society because of its semi-volatility, persistence, complex environmental chemistry, and tendency to bioaccumulate in fish. The draft mercury options paper (GLNPO 1995) proposed regulatory and voluntary measures to prevent or reduce atmospheric mercury contamination, and introduced the concept of the mercury "life cycle." A comprehensive approach to virtually eliminating mercury releases was proposed:

- Increase public awareness of mercury problems and mercury-containing items;

- Influence supply of mercury to minimize primary production and manage federal holdings;

- Minimize use of mercury through pollution prevention and alternative technologies;

- Reduce uncontrolled releases by encouraging recycling and regulating releases; and

- Manage disposal of mercury-containing items and mercuric wastes.

Regulatory and Voluntary Options that may Prevent or Reduce Atmospheric Mercury Contamination

♦ **Pollution Prevention.** Mercury use in the United States has substantially declined during the past two decades. This trend parallels that of western Europe. Ebbing use implies that less mercury will be included in waste streams reaching incinerators and landfills, or released during production processes. The decline in use is attributable to both government bans and technological advances that create environmentally safer products. Mercury has been banned in pesticides (1972-1976 and 1993) and in paints. The number of U.S. chloralkali facilities using a mercury cell process has declined from 25 during the early 1970s to 14 in recent years. Minnesota, Wisconsin, and New York restricted mercury content in batteries, and consequently, national use of mercury in batteries fell from 448 tons during 1988 to 10 tons during 1993. Mercury content in fluorescent bulbs has also declined.

♦ **Recycling.** A number of users of mercury are taking steps to boost recycling. Various municipal wastewater treatment plants are working with dental associations to encourage recovery of mercury in dentist offices so that mercury amalgam does not enter their treatment systems. Some manufacturers who rely on mercury in instruments are starting or considering take-back programs; EPA and states are working with several such firms to ensure that liability concerns do not preclude voluntary efforts. A number of hospitals are diverting mercury-containing wastes from incineration. Several states require that fluorescent bulbs be recycled (e.g., Florida, Minnesota), because such bulbs are commonly broken in or en route to landfills, allowing mercury vapors to escape to the atmosphere. While the quantity of mercury contained in a single bulb is minuscule, the number of discarded bulbs is great.

♦ **Management.** Pursuant to implementation of the CAA, EPA has proposed performance standards for municipal and medical waste incinerators. A final rule for municipal waste combustors (new sources with individual capacity of >250 tons/day) was promulgated in December 1995 (60 *Federal Register* 65387) and a proposed rule for medical waste incinerators in June 1996 (61 *Federal Register* 31736). There are about 2,400 medical and 180 municipal incinerators across the nation. These sectors are estimated to generate about one-half of current national emissions of mercury, primarily through combustion of discarded products that contain mercury. When fully implemented by 2002 through state plans, these proposed standards hold promise of reducing mercury emissions from these two classes of incinerators by 95 and 80 percent, respectively. Performance standards will also be evaluated for other sectors that also emit mercury, including the Portland Cement industry; commercial and industrial boilers; primary lead smelters; the chloralkali sector; primary copper smelters; sewage sludge incinerators; and lime manufacturing.

♦ **Global Production and Release of Mercury.** During recent years, the U.S. government has held a significant stockpile of mercury on the world commodity market. To dispose of its holding, the Department of Defense has periodically auctioned mercury. From 1988 through 1993, sales totaled four million pounds. Sales were suspended in 1994, pending consideration of their environmental impacts. One positive environmental impact of sales is that they may forestall virgin production of mercury; the last mercury mines in the United States closed several years ago. Both western Europe and the United States have become substantial net exporters as their mercury consumption has fallen, whereas world use may be growing (Lawrence 1994). Because of diminished use of mercury, the United States is nearly meeting its entire need for mercury through recycling. Much of the mercury sold by the federal government has been exported. Foreign use and release, due to less stringent controls, can contribute to global atmospheric contamination which can travel for long distances, and directly contaminate U.S. surface waters. Suspension of government sales has positioned the United States to seek needed international cooperation in minimizing mercury releases on a global scale.

The Great Lakes Binational Toxics Strategy. The *Canada-United States Strategy for the Virtual Elimination of Persistent Toxic Substances in the Great Lakes*, also known as the Binational Great Lakes Toxics Strategy, was signed between the two countries on April 7, 1997 (U.S. EPA and Environment Canada 1997). This Binational Strategy was developed jointly by EPA and Environment Canada, in keeping with the objectives of the 1987 GLWQA. Both Canada and

United States have domestic virtual elimination strategies but a coordinated strategy is necessary for the greatest reduction in toxic substances throughout the Basin. Both nations encourage and support voluntary programs by all stakeholders to reduce the generation, use, and release of toxic substances to the Great Lakes.

The Binational Strategy provides the framework to achieve quantifiable goals in a specified time frame (1997 to 2006) for targeted persistent toxic substances, especially those which bioaccumulate. Flexibility is provided in the Strategy to allow for the revision of targets, time frames, and the list of pollutants. All actions and activities, both regulatory and nonregulatory, will be considered to help speed reductions. The Strategy also recommends that goals be accomplished through a four-step process (see sidebar). The pollutants identified in the Strategy fall into two lists. The Level I substances represent an immediate priority and are targeted for reduction and eventual virtual elimination through pollution prevention and other incentive-based actions. These pollutants are aldrin/dieldrin, benzo(a)pyrene, chlordane, DDT/DDE/DDE, hexachlorobenzene, alkyl lead, mercury and mercury compounds, mirex, octachlorostyrene, PCBs, dioxins/furans, and toxaphene. For pollutants that are considered Level II substances, the governments encourage stakeholders to undertake pollution prevention activities to reduce levels in the environment of those substances nominated jointly by both countries, and to conform with the laws and policies of each country, including pollution prevention, with respect to those substances nominated by only one country, until and unless these pollutants are placed on the Level I list. The Level II pollutants are cadmium and cadmium compounds, 1,4-dichlorobenzene, 3,3'-dichlorobenzidine, dinitropyrene, endrin, heptachlor (and heptachlor epoxide), hexachlorobutadiene (and hexachloro-1,3-butadiene), hexachlorocyclohexane, 4,4'-methylenebis(2-chloroaniline), PAHs, pentachlorobenzene, pentachlorophenol, tetrachlorobenzene (1,2,3,4- and 1,2,4,5-), and tributyl tin.

A Four-Step Process Toward Virtual Elimination

1. Gather information on generation, uses, and sources of the pollutant within and outside the Great Lakes Basin;

2. Analyze current regulatory and non-regulatory programs and initiatives that manage or control the pollutants and identify the gaps in these regulations that offer opportunities for reductions;

3. Develop cost-effective options and provide recommendations for increasing the pace and level of reductions; and

4. Recommend and implement actions to achieve goal.

Both the United States and Canada have set "challenge" goals to achieve reductions through implementation of voluntary efforts and regulatory actions. One of these challenges is the commitment of these countries to work together to assess atmospheric inputs of persistent toxic substances to the Great Lakes, with the goal of evaluating and reporting jointly on the contribution and significance of long-range transport of these substances from worldwide sources. Efforts will be made to work within the existing international framework to reduce releases of such pollutants from remaining long-range sources. Activities by EPA and Environment Canada to meet this particular challenge include:

- Coordinate efforts to identify sources in order to better define and coordinate emission control programs;

- Maintain atmospheric deposition monitoring stations to detect deposition and transport of toxic substances;

- Continue research on atmospheric science of toxic pollutants to refine and to improve existing source, receptor, and deposition models, as well as improve integration of existing air toxic monitoring networks and data management systems to track deposition of contaminants within the Great Lakes; and

- Conduct an assessment of long-range transport of persistent toxic pollutants from worldwide sources

In addition to these coordinated binational efforts, Environment Canada will also demonstrate alternative processes to lessen emissions from five predominant sources by 2001 and complete inventories of 10 selected air pollution sources to support assessment of environmental impacts of air toxics by 1999.

Besides the above challenge, the Strategy includes several specific reduction goals or challenges for the Level I pollutants (Table IV-3). For the United States, the baseline from which these reductions will be measured will be the most recent and appropriate inventory (e.g., mercury will be based on estimated emissions during the early 1990s). Canada plans to use their 1988 emissions inventory.

Two additional challenges from the Strategy are: (1) complete or be well advanced in remediation of priority sites with contaminated bottom sediments in the Great Lakes Basin by 2006; and (2) promote pollution prevention and sound management of Level II substances, to reduce levels in the environment. The Binational Strategy is intended to fill in the gaps that exist where ongoing programs or emerging initiatives do not address toxic releases, to provide a context of basinwide goals for localized actions, and to provide "out of basin" support to programs such as LaMPs.

LAKEWIDE MANAGEMENT PLANS (LaMPS)

In Article VI, Annex 2 of the GLWQA, the U.S. and Canadian governments agreed to develop and implement LaMPs for each of the five Great Lakes. The purpose of the LaMPs is to document an approach to reducing input of critical pollutants to the Great Lakes and restoring and maintaining Great Lakes integrity. LaMPs are management tools designed to (1) integrate federal, state, provincial, and local programs to reduce loadings of toxic substances from both point and nonpoint sources; (2) assess whether these programs will ensure attainment of water quality standards and designated beneficial uses; and (3) recommend any media-specific program actions or enhancements to reduce toxic loadings in waters currently not attaining water quality standards and/or designated beneficial uses. Unlike the other four Lakes, Lake Michigan lies entirely within the boundaries of the United States and therefore, the Lake Michigan LaMP has been developed solely by U.S. federal and state agencies with input from a public forum. The development of this program, as well as the deadlines established for the completion of the program, is mandated under section 118 of the CWA. In addition, as noted in Chapter I, section 112(m) of the CAA requires that EPA, in cooperation with NOAA, monitor the Great Lakes, investigate atmospheric deposition rates and pollutant sources, improve monitoring methods, and determine the relative contribution of atmospheric pollutants to the total pollution loadings to the Great Lakes and other Great Waters.

TABLE IV-3
Specific Pollutant Reduction Goals Under the Great Lakes Binational Toxics Strategy [a]

Level I Substances	United States Challenge	Canadian Challenge
Aldrin/Dieldrin, Chlordane, DDT, Toxaphene, Mirex, Octachlorostyrene	Confirm by 1998 that there is no longer use or release from sources that enter Great Lakes Basin. If ongoing long-range sources from outside of U.S. are confirmed, use existing international frameworks to reduce or phase out releases.	Report by 1997 that there is no longer use, generation, or release from Ontario sources that enter Great Lakes Basin. If ongoing long-range sources outside of Canada are confirmed, use existing international frameworks to reduce or phase out releases.
Alkyl lead	Confirm by 1998, there is no longer use in automotive gasoline; support and encourage stakeholder efforts to reduce releases from other sources.	Seek by 2000, 90 percent reduction in use, generation, or release.
PCBs	Seek by 2006, a 90 percent reduction nationally of high level PCBs (>500 ppm) in electrical equipment; ensure all PCBs retired from use are properly managed and disposed of to prevent accidental releases within or to the Great Lakes Basin.	Seek by 2000, a 90 percent reduction nationally of high-level PCBs (>1 percent PCBs) that were once, or are currently, in service and accelerate destruction of stored high-level PCB wastes that may enter the Great Lakes Basin.
Mercury [b]	Seek by 2006, a 50 percent reduction nationally in deliberate use of mercury and a 50 percent reduction in release from sources resulting from human activity. [c]	Seek by 2000, a 90 percent reduction nationally in releases of mercury, or where warranted the use of mercury, from polluting sources resulting from human activity in the Great Lakes Basin.
Dioxins/Furans	Seek by 2006, a 75 percent reduction in total releases of dioxins/furans (2,3,7,8-TCDD toxicity equivalents) from sources resulting from human activity. [c]	Seek by 2000, a 90 percent reduction in releases of dioxins/furans (focus on 2,3,7,8-substitute congeners) from sources resulting from human activity in Great Lakes Basin.
Benzo(a)pyrene, HCB	Seek by 2006, reductions in releases that are within or may have potential to enter the Great Lakes Basin from sources resulting from human activity.	Seek by 2000, a 90 percent reduction in releases from sources resulting from human activity in the Great Lakes Basin.

[a] Detailed descriptions of these challenges are presented in The Great Lakes Binational Toxics Strategy (U.S. EPA and Environment Canada 1997).
[b] Mercury challenges are considered interim reduction targets for mercury and, in consultation with stakeholders, will be revised if warranted, following completion of EPA's Mercury Study Report to Congress (U.S. challenge) and 1997 *Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem* (Canadian challenge).
[c] The release challenge applies to the aggregate of releases to the air nationwide and of releases to the water within the Great Lakes Basin.

A LaMP is a dynamic, action-oriented process encompassing a number of components. These include an evaluation of beneficial use impairments and pollutants contributing to those impairments; a summary of sources and loads of these critical pollutants; identification of ongoing prevention, control, and remediation actions, as well as additional efforts needed to reduce pollutant loads and to restore beneficial uses; and monitoring activities to evaluate the effectiveness of program actions. This approach for developing and implementing LaMPs is an evolutionary and iterative process for identifying and reducing critical pollutants. Public

participation and cooperation with states and local governments is a key component to the LaMP development process.

LaMPs are in various stages of development for each of the Great Lakes (see sidebar). Not all of the Lakes have LaMPs published in the Federal Register; however, commitments have been made by key stakeholders in the respective basins to pursue toxics reduction. Actions are being taken to achieve this goal. Each LaMP addresses a different list of critical pollutants, but some common ones are mercury, PCBs, hexachlorobenzene, dioxins, furans, chlordane, DDT and metabolites, and dieldrin (all of which are Great Waters pollutants of concern).

Current Status of LaMPs in the Great Lakes

Superior Binational Program to Restore and Protect the Lake Superior Basin announced (1991)

Stage 1 LaMP submitted to IJC (1995)

Stage 2 LaMP released for public review (1996)

Michigan LaMP published in Federal Register (1994)

Huron LaMP not established

Erie LaMP Management Committee formed (1994)

Ontario Lake Ontario Toxics Management Plan (1989)

LaMP Workplan signed (1993)

Several activities have been initiated through LaMPs:

♦ In the Lake Michigan basin, agricultural "clean sweeps" to properly collect and dispose of unused pesticides have been conducted in Indiana, Michigan, and Wisconsin. Also, a variety of pollution prevention and technical assistance projects have taken place in Milwaukee, Chicago, and western Michigan.

♦ In most lake basins, tributary and atmospheric deposition monitoring is occurring. The Lake Michigan LaMP is utilizing the information generated from the Lake Michigan Mass Balance Study (described earlier in the section) to identify and reduce loadings as data become available.

♦ The Lake Superior LaMP was initiated as a component of the binational efforts to restore and protect Lake Superior. One of the goals of the LaMP is to achieve zero discharge and emission of persistent toxic pollutants through its Zero Discharge Demonstration Project. Another effort of the Lake Superior LaMP is an extensive pollution prevention outreach and education program developed for mercury. Among the activities are battery collection, energy efficiency, and product takeback programs. For example, Honeywell, Inc., the largest manufacturer of mercury thermostats used in regulating heating in the home, has instituted a thermostat takeback program in which the company recycles the mercury.

The LaMPs often provide the needed coordination and oversight for many such projects being implemented all over the Great Lakes Basin.

THE GREAT LAKES WATER QUALITY (GLWQ) GUIDANCE

Another notable toxics reduction effort was the GLWQ Guidance (U.S. EPA 1995a). It is the culmination of a six-year cooperative effort that included participation by the eight Great

Lakes states, the environmental community, academia, industry, municipalities, and EPA's regional and national offices, and stems from the Great Lakes Water Quality Initiative, which began when the states of the Great Lakes Region recognized the important feature of the Great Lakes ecosystem to accumulate persistent pollutants.   The guidance is not only designed to address existing problems, but also to prevent emerging and potential problems posed by additional chemicals in the future, which may damage the overall health of the Great Lakes system. The guidance includes criteria for the protection of human life, wildlife, and aquatic life, taking into account the ability of many pollutants to biomagnify. Antidegradation requirements assure that current water quality will not be diminished. The guidance also outlines procedures to ensure consistent implementation and appropriate flexibility for long-term protection of the Great Lakes.

The GLWQ Guidance promotes the use of pollutant minimization plans to stop pollution before it enters the environment. Reducing pollution at its source is the most effective way of protecting public health and the environment, and is often more economical than cleaning up after a pollutant is released.

The water quality criteria in the GLWQ Guidance apply to all of the waters in the Great Lakes system, regardless of the source of pollution. Pollutants enter the Great Lakes from the air, stirred-up bottom sediments, urban and agricultural runoff, hazardous waste and Superfund sites, spills, and industrial and municipal wastewater discharges. Although the implementation procedures of the guidance apply mostly to industrial and municipal water discharges, a state may find it is more effective (or cost-effective) to improve water quality by reducing air emissions or cleaning up contaminated sediments, and may choose not to impose additional requirements on wastewater dischargers.

GREAT LAKES REMEDIAL ACTION PLANS

The 1978 GLWQA, along with the 1987 amendments, established guidelines for restoring the quality of the Great Lakes. As a response to this measure, geographical "problem areas" or Areas of Concern (AOCs) were identified in the Great Lakes where GLWQA objectives had been exceeded and such exceedance had caused, or was likely to cause, impairment of beneficial use or the area's ability to support aquatic life. The defined AOCs include rivers, connecting channels, harbors, and embayments of the Great Lakes, with the U.S. states and Canadian provinces responsible for remediating these areas. The Water Quality Board (WQB) of the IJC determines the AOCs, but the specific geographical boundaries of the AOCs are set by the states and/or provincial governments. Currently, there are 43 AOCs; 12 are under Canadian jurisdiction, 26 under U.S. jurisdiction, and five under jurisdiction of both countries. The sources of contamination have usually been water discharges from point and non-point sources.

In order to provide more uniform guidance on how to remediate the AOCs, Remedial Action Plans (RAPs) were introduced in 1985. In 1994, eight U.S. states were involved in the RAP process: Indiana, Illinois, Minnesota and Pennsylvania (1 AOC each), Ohio (4 AOCs), Wisconsin (5 AOCs), New York (6 AOCs), and Michigan (14 AOCs). Currently, for most AOCs, the problem definition stage of the RAP process has been addressed and the planning and implementation stages are to be initiated. One of the major problems facing the AOCs today is toxic contamination of the sediments. All of the U.S. AOCs have impaired beneficial uses attributable to contaminated sediments (U.S. EPA and Environment Canada 1994). As a result, sediment remediation is a key component of RAP remediation.

The progress of AOC remediation is presented in an EPA report, *Progress in the Great Lakes Remedial Action Plans: Implementing the Ecosystem Approach in the Great Lakes Areas of Concern* (U.S. EPA and Environment Canada 1994). This report provides an update for each AOC in the Great Lakes and summarizes the major barriers to and benefits of the RAP process. It concludes that a comprehensive decision-making process that leads to commitment for action is an essential aspect of implementing an ecosystem approach, as required in a RAP. Great Lakes federal, state, and provincial governments have provided leadership and resources for development and implementation of RAPs. Through government and community-based partnerships, RAPs are being developed to be a coordinated, multi-stakeholder response to restoring impaired beneficial uses in AOCs.

SOME ADDITIONAL ACTIONS RELATED TO TOXIC CONTAMINATION AND REDUCTION

In addition to activities described above, many pollutant-specific efforts provide significant information on atmospheric contamination in the Great Lakes. For example, EPA developed standards for municipal waste combustors (excludes new sources with individual capacity of ≤250 tons/year) (60 *Federal Register* 65387) and proposed standards for medical waste incinerators (61 *Federal Register* 31736) which will, when implemented by 2002, provide about a 70 ton reduction in mercury emissions, or 35 percent of current total U.S. emissions, based on 1990 emissions estimates. Implementation of other Maximum Available Control Technology (MACT) standards, including those proposed in 1996 for hazardous waste combustors, offer the probability of further mercury emission reductions in the future.

For toxaphene, many issues remain about its sources and continuing presence in the Great Lakes. EPA held a research workshop on March 27-29, 1996, with scientists to assess these concerns (U.S. EPA 1996c). Based on the meeting, the following actions were recommended to maintain progress toward resolving several questions concerning concentrations and trends (spatial and temporal) in various Great Lakes media and the sources of toxaphene in the Great Lakes:

- Measure concentration gradient of toxaphene across air-water interface and link with atmospheric source profile to establish seasonal and annual fluxes to and from Lakes Superior and Michigan, as well as correlative measurements in other Great lakes to permit spatial comparisons;

- Collect additional sediment cores in Lakes Superior and Michigan to determine concentrations, accumulation rates, and inventories to help establish past dynamics of toxaphene and assist in efforts to forecast future conditions in the Great Lakes;

- Quantify aquatic food web dynamics to establish how food web influences spatial and temporal variations in toxaphene concentrations in biota.

- Measure physical-chemical properties of toxaphene homologs and congeners.

Besides providing information on sediment deposition and cycling of toxaphene in the Great Lakes, it is anticipated that results from these recommendations would provide a more firm technical basis upon which to explore the need for and extent of appropriate management actions.

Another major binational effort to broadly address Great Lakes issues is the State of the Lakes Ecosystem Conference (SOLEC) organized by the governments of the United States and Canada. In the first SOLEC in 1994, a report (and five background papers) was released on the current condition of the Great Lakes (Environment Canada and U.S. EPA 1995). The report addressed the entire Great Lakes system in terms of ecological and human health, and the stressors which affect it. The six areas of discussion were human health; aquatic community health; aquatic habitat; toxic contaminants; nutrients; and the economy. Although the report did not describe or evaluate pollution control or natural resource management programs, it did focus on environmental conditions within the Great Lakes system. The SOLEC report indicated that there has been considerable improvement in all the Great Lakes compared to 30 years ago, although serious losses in habitat for native plants and animals continues. Nutrient and toxic

> **State of the Lakes Ecosystem Conference (SOLEC)**
>
> As part of the continuing response by the governments of the United States and Canada to the binational Great Lakes Water Agreement, SOLEC was initiated and held in October 1994. The second meeting of SOLEC was held in Windsor, Ontario, on November 6-8, 1996. SOLEC is viewed as part of a process of sharing information needed to make well informed decisions that affect the ecosystem of the Great Lakes. It is attended by managers and other decision makers from the private sector, and government and non-government environmental organizations.

contaminant concentrations appear to be decreasing, although bioaccumulative pollutants still cause problems. The report presented a "mixed picture" of the current conditions of the Great Lakes and challenges managers and decision makers throughout the basin to obtain adequate information, deal with subtle effects of long-term exposure to low levels of toxic contaminants, protect biodiversity, restore habitat for native plants and animals, connect decisions with ecosystem results, and attain sustainability.

Building on the findings of the first SOLEC, the 1996 SOLEC (Environment Canada and U.S. EPA 1996) focused on nearshore areas of the Great Lakes basin (i.e., warm and shallow waters, coastal wetlands). These areas represent the most diverse and productive parts of the Great Lakes ecosystem, and provide support for most intense human activity and subsequently, are subjected to greatest stress. Key themes from the conference were immediate actions; local/community level involvement; development of common ecosystem health indicators to measure progress; essentiality of cooperation and partnership due to complexity of issues and development of new ideas; approaches that recognize long-term perspective; and focus on prevention and preservation. The Great Waters program will benefit from many aspects of SOLEC, such as the information gathered on the impact of air pollutants on human health and ecological effects and the promotion of pollution prevention measures.

Addressing Data Gaps/Future Needs

Considerable progress has been made in the recent past in characterizing and reducing toxic pollution in the Great Lakes. The programs presented above and summarized in Table IV-4 provide an overview of some notable and recent activities by the United States, as well as Canada, to respond to concerns related to atmospheric pollution in the Great Lakes. Some of these measures include identifying emission sources; characterizing contamination from

TABLE IV-4
Summary of Some Major Programs to Address Atmospheric Contamination in the Great Lakes

Data Collection/Research Projects

Lake Michigan Monitoring Program/Lake Michigan Mass Balance Study	Scientific base for future load reduction effort at all government levels. Mass balance study addresses CAA section 112(m) through coordinated effort to quantify and understand loadings, transport, and fate of selected HAPs. Also to provide a validated method to estimate loading for other waterbodies.
Integrated Atmospheric Deposition Network (IADN)	Binational monitoring network and research program to determine magnitude and trends of atmospheric deposition for the region.
Great Lakes Emissions Inventories	Inventory of sources and source category emissions in Great Lakes region, with a multi-state data base (RAPIDS).

Toxics Reduction Efforts

Virtual Elimination Pilot Program/ Great Lakes Binational Toxics Strategy	Regulatory and non-regulatory efforts to encourage reduction in use and release of bioaccumulative pollutants in Great Lakes.
Lakewide Management Plan (LaMP)	Management tool to document approach to decrease pollutant input to each of the Great Lakes.
Great Lakes Water Quality (GLWQ) Guidance	Promotion of pollution minimization plans to stop pollution before it reaches the environment, and consistent standards to protect human health, wildlife, and aquatic life.
Remedial Action Plans for Great Lakes Areas of Concern (AOCs)	Action-planning process for implementing remedial and preventive actions to restore impaired beneficial uses of specific areas.

pollutants; developing and implementing voluntary and regulatory measures; and developing guidance for evaluating levels of risk of pollutant contamination. These programs have usually involved coordination among various federal, state, and/or local agencies. Though each program is designed to address specific goals, many of these programs coordinate their efforts to ensure that results are not duplicated. For example, the Binational Virtual Elimination Strategy was developed to achieve virtual elimination of persistent toxic pollutants in the Great Lakes, but it also supports and builds upon ongoing processes in the LaMPs, such as the Zero Discharge Demonstration Project through the Lake Superior LaMP. Furthermore, the Great Lakes Emissions Inventories will eventually provide information for determining whether the reduction goals set in the Great Lakes Binational Toxics Strategy have been met. The IADN will monitor whether pollutant levels are actually decreasing.

The Great Lakes programs described in this chapter also complement the Great Waters program in assessing and identifying the extent of atmospheric contamination of hazardous air pollutants to the Great Lakes. Further coordinated progress is needed to improve knowledge and understanding of pollutant contamination, as well as to increase public awareness. In addition to the continuation of the current programs/activities, some high priority efforts for the Great Lakes basin include:

♦   Improvement in research and monitoring techniques to reduce uncertainties in loading calculations (such as those for the IADN) and therefore, result in better estimates of atmospheric pollutant levels and deposition;

♦   Improvement in dispersion and deposition models currently being developed to link emission inventory information to atmospheric loadings of Great Lakes pollutants at the water's surface;

♦   After Lake Michigan Mass Balance data have been analyzed, application of results and modeling tools from the study to the development of a general mass balance model for other hazardous air pollutants;

♦   Increase in efforts to identify local and long-range sources of Great Lakes pollutants through various source apportionment modeling and emissions inventories, such as in the RAPIDS data base; and

♦   Continuation of efforts to develop and implement strategies and recommendations to reduce use, generation, and release of pollutants affecting the Great Lakes, particularly through binational efforts such as the reduction challenges proposed under the Binational Virtual Elimination Strategy.

As more information is gathered on the characterization and reduction of atmospheric deposition of toxic pollutants to the Great Lakes, the results of these efforts, as well as the tools used, may be applied to other waterbodies, such as Lake Champlain.

IV.B Lake Champlain

Located around the northernmost borders of the states of New York and Vermont and the southern border of the province of Quebec, Lake Champlain is one of the largest freshwater lakes in the United States, with 1,127 km^2 of surface water, over 70 islands, and 945 km of shoreline (see Figure IV-6). It flows north from Whitehall, New York, almost 193 km across the U.S.-Canadian border to its outlet at the Richelieu River in Quebec, where it joins the St. Lawrence River. Lake Champlain is unique because of its narrow width (19 km at its widest point), great depth (over 122 meters in some parts), and large size of the watershed relative to the lake surface.

The Lake Champlain Basin, composed of the entire watershed or drainage area, spans from the Adirondack Mountains in the west to the Green Mountains in the east, and from the Taconic Mountains in the southeast to the St. Lawrence Valley in the north (Figure IV-6). The total area of the Basin is 21,326 km^2, of which 56 percent is in Vermont, 37 percent is in New York, and 7 percent is in Quebec. The Basin is characterized by an 18:1 ratio of watershed to lake surface area, indicating that the lake represents only about 5 percent of the total basin area. Approximately 89 percent of the Basin is categorized as forest and agricultural land.

By the end of 1994, approximately 645,000 people resided in the Lake Champlain Basin, with the population increasing each year by about 1.2 percent (LCBP 1994). Most of the region is classified as rural, with only Burlington, Vermont, recognized as a metropolitan area (1990 population of 52,000). The Lake Champlain Basin has traditionally had a rural resource-based economy, including agriculture, renewable natural resources (e.g., timber, fish, maple syrup), and non-renewable natural resources (e.g., iron ore, marble, gravel). In recent years, the economy has diversified into other activities, but is still dependent on the natural resources (see sidebar).

**Economic Highlights of
Lake Champlain Basin**

- Twenty-five percent of the workforce is employed in natural resource-related activities (e.g., agriculture, mining, forestry).

- Resources of the Lake are a major reason why many Basin residents reside in this region.

- Tourism represents a significant economic factor for the region, generating $2.2 billion in 1990, of which 40 percent were Lake related (e.g., marina, white-water rafting). Part of tourism income comes from recreational activities, including $81 million per year from fishing industry (in 1991) and $50 million per year from bird and wildlife viewing (in 1990).
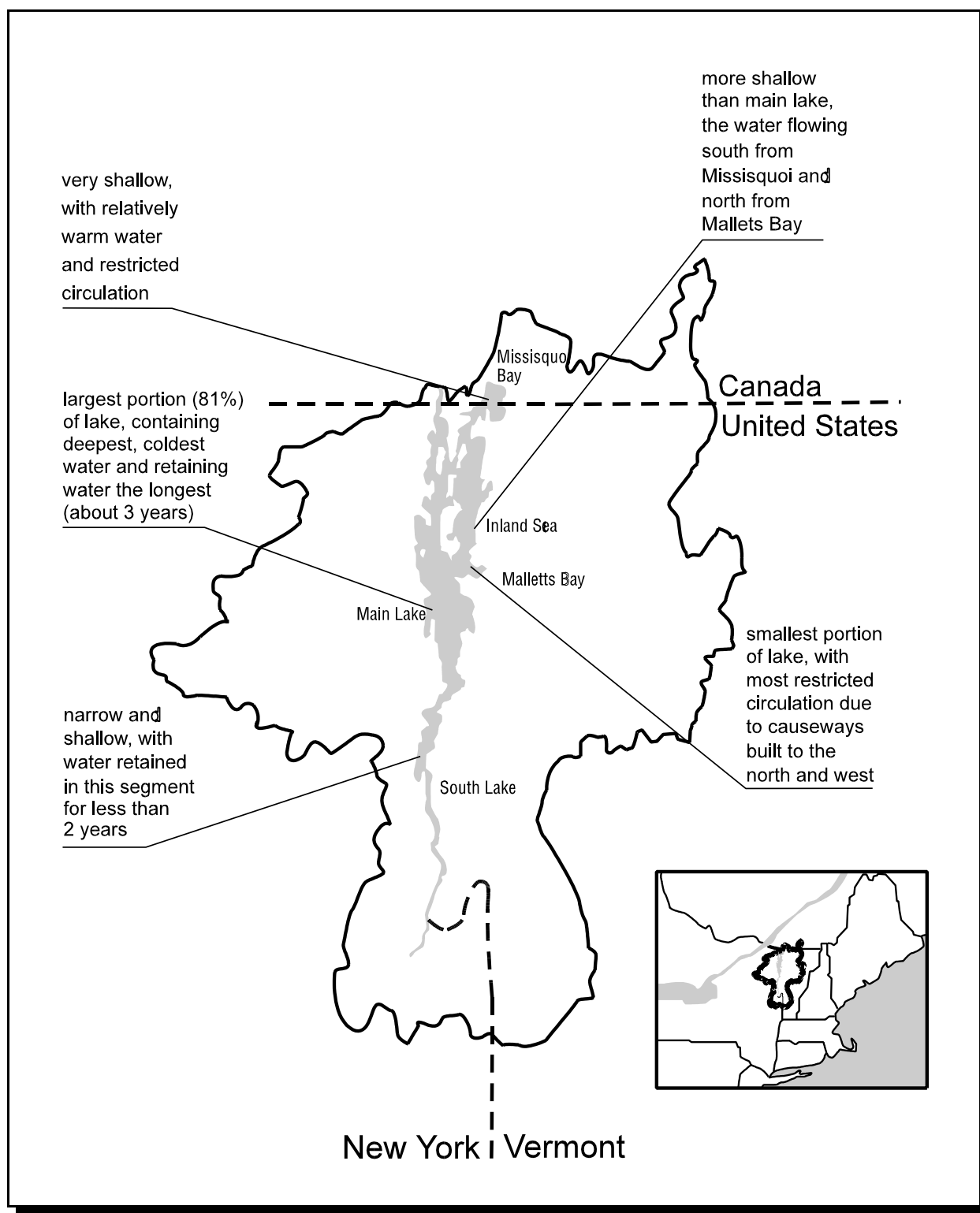
Sources: LCBP 1994, 1996.

Lake Champlain, unlike many other lakes that tend to be more evenly mixed, is made up of five distinct areas or lake segments, each with different physical and chemical characteristics (Figure IV-6). In these lake "divisions," pollutants may accumulate in shallow areas or bays where flushing and water circulation are reduced, and may be deposited at the mouths of rivers where runoff carrying sediment and other pollutants from the watershed is discharged. Human activities also concentrate in many of these areas of the lake, increasing the potential for contamination and exposure.

FIGURE IV-6
Lake Champlain Basin

more shallow
than main lake,
the water flowing
south from
Missisquoi and
north from
Mallets Bay

very shallow,
with relatively
warm water
and restricted
circulation

largest portion (81%)
of lake, containing
deepest, coldest
water and retaining
water the longest
(about 3 years)

narrow and
shallow, with
water retained
in this segment
for less than
2 years

Missisquoi
Bay

Canada
United States

Inland Sea

Malletts Bay

Main Lake

smallest portion
of lake, with
most restricted
circulation due
to causeways
built to the
north and west

South Lake

New York | Vermont

An understanding of the hydrodynamics of Lake Champlain is essential to predicting how and where pollutants are transported, and where they will end up in the lake. A simplified three-dimensional hydrodynamic transport model, being developed with funding by the Lake Champlain Basin Program (LCBP), will be used as a management tool to determine potential effects of pollutant inputs and other changes to the waterbody (LCBP 1994).

Characterizing Toxic Contaminants in Lake Champlain

Levels of toxic contamination in Lake Champlain are low compared to the Great Lakes; however, concerns for protecting the public health still exist. Fish consumption advisories for two Great Waters pollutants (mercury and PCBs) are currently in effect in both New York and Vermont for fish from Lake Champlain (see Appendix B) (LCBP 1994). Testing of lake bottom sediment near the urbanized sites along the Lake shows pollutants levels that may be of concern and indicates potential risks to aquatic life (see Section II.B). Because of these findings, as well as exceedances of water quality standards set by EPA, NOAA, and the province of Ontario, LCBP gives highest priority to these two pollutants.

The contribution of air deposition as a source of loadings for pollutants, such as metals and organic compounds, is of concern for Lake Champlain and the Basin, and has been the subject of recent studies. Although emissions of toxic pollutants within the Basin are considered low because of the few industries and utilities in the local area, high levels of pollutants may reach the Lake from more distant sources (LCBP 1994, 1996). Data have been limited regarding atmospheric sources, or the movement of pollutants from the atmosphere to the Lake directly or through the watershed.

Atmospheric Sources of Toxic Contamination in Lake Champlain	
Local	Mobile emissions
	Residential energy consumption (e.g., wood burning)
	Waste incinerators
Regional/ Long-distance	Smelters (Quebec)
	Utilities (midwestern United States)

A 1990/1991 air monitoring study measured the concentration of toxic metals at four sites in the Lake Champlain Basin (Whiteface Mountain, NY; Willisboro Bay, NY; Burlington, VT; and Underhill, VT) (LCBP 1994). Preliminary data revealed elevated levels of zinc in the air surrounding Burlington, possibly due to refuse incineration, tire wear, and industries. There were also periodic increases in arsenic levels at these and other sites across the Northeast. The source of these arsenic concentrations in the air is believed to be a smelter in Quebec (LCBP 1994). Mercury, lead, and cadmium compounds were also measured in this study; however, there was no indication that the concentrations for these Great Waters pollutants of concern were of concern at the monitoring sites.

The following subsection focuses on currently ongoing mercury research to determine atmospheric deposition to the Lake Champlain Basin. Information on atmospheric deposition of the other high priority pollutant to the basin, PCBs, is lacking at this time.

ATMOSPHERIC DEPOSITION OF MERCURY IN THE LAKE CHAMPLAIN BASIN

Mercury burden in Lake Champlain is evidenced by fish consumption advisories. Direct discharges of mercury are quite limited which has led to concerns that the atmosphere may be the major route of mercury to the lake. Recent studies supported by NOAA and EPA's Great Waters program have investigated the deposition of atmospheric mercury in the Lake Champlain Basin (Burke et al. 1995; Scherbatskoy et al. 1997). The air monitoring data collected from these efforts should provide an initial framework for a more comprehensive analysis of mercury cycling (i.e., deposition, transport, transformation, and accumulation) in the region, and beyond. There is currently no information that compares the estimated amount of mercury entering the lake via water (e.g., runoff) with the amount deposited from the air.

Atmospheric mercury concentration and deposition in Lake Champlain was investigated at a location just east of the Lake in Underhill, Vermont, between 1992 and 1994 (Scherbatskoy et al. 1997). The atmospheric concentration of mercury was measured as gaseous and particulate phases in the ambient air and in precipitation (snow, rain) (see sidebar). Findings on the atmospheric mercury levels near Lake Champlain are presented below and in Figure IV-7:

♦ *Atmospheric gaseous mercury concentration.* Average gaseous concentration for 1993 was 1.94 ng mercury/m^3 (comparable to other sites near the Great Lakes), staying relatively constant throughout the year (Table IV-5). Concentrations are typically two orders of magnitude (100 times) higher than particulate mercury.

♦ *Average particulate phase mercury concentration.* Unlike the gaseous phase, particulate phase mercury in the air exhibited seasonal variability, with levels higher in winter than in summer (Figure IV-7). The source of the increased particulate mercury concentration in the winter has not been identified, but preliminary meteorological analysis suggests that a more regional influence is important in the transport of particulate phase mercury in the winter, due to higher average wind speeds and colder temperatures during this season. It also is suggested that colder temperatures in the winter may favor condensation of gas onto particles, increasing mercury particulate concentration in the atmosphere (Scherbatskoy et al. 1997). Furthermore, daily mercury concentrations did not fluctuate significantly, as would be expected for strong local sources.
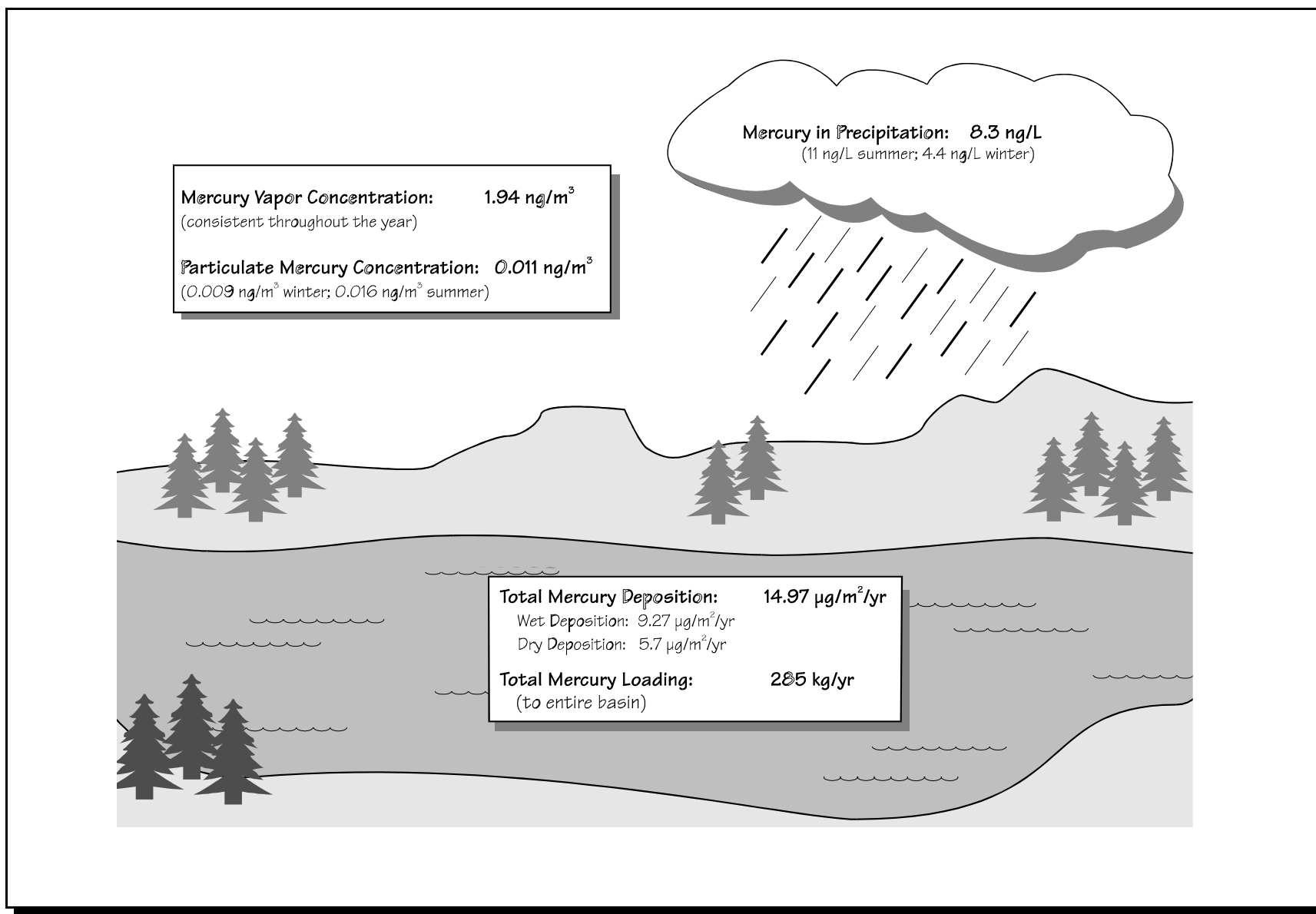

Principal Phases of Atmospheric Mercury

Gaseous (Vapor) Phase Mercury: consists primarily of elemental mercury (Hg°; predominant form in the atmosphere), although divalent mercury (Hg^{+2}) may also be present; Hg^{+2} is deposited more rapidly than elemental mercury.

Particulate Phase Mercury: consists of fine particles that are not readily deposited from the atmosphere; bound Hg^{+2} is the predominant form and exists as the nucleus in dust particles.

Mercury in Precipitation: consists of mercury either as dissolved gas or bound to fine particles; primarily particulate Hg^{+2} that has been taken up by rain droplets.

FIGURE IV-7
Atmospheric Mercury in Lake Champlain Basin [a]

Mercury in Precipitation: 8.3 ng/L
(11 ng/L summer; 4.4 ng/L winter)

Mercury Vapor Concentration: 1.94 ng/m^3
(consistent throughout the year)

Particulate Mercury Concentration: 0.011 ng/m^3
(0.009 ng/m^3 winter; 0.016 ng/m^3 summer)

Total Mercury Deposition: 14.97 μg/m^2/yr
    Wet Deposition: 9.27 μg/m^2/yr
    Dry Deposition: 5.7 μg/m^2/yr

Total Mercury Loading: 285 kg/yr
    (to entire basin)

[a] Values are annual average, unless otherwise specified.   Source: Scherbatskoy et al. 1997

TABLE IV-5
Comparison of Mean Total Atmospheric Mercury Concentrations [a]
(Gaseous and Particulate Phases and in Precipitation)

Location	Gaseous Phase (ng/m^3)	Particulate Phase (ng/m^3)	Precipitation (ng/L) (volume-weighted)
Lake Champlain	1.94 ± 0.5	0.011 ± 0.007	8.3 ± 5.2
Northern Michigan[b]	NA	0.011	7.9 ± 7.4
Southern Michigan[b]	NA	0.022	10.2 ± 9.8
Northern Wisconsin[c]	1.57 ± 0.4	0.02 ± 0.02	10.5 ± 4.8
Northern Wisconsin[d]	1.8 ± 0.4	0.01 ± 0.02	6.7 ± 5.6

NA = Not Available
[a] Data are means for varying years and periods; different sampling methods for the studies.
Gaseous and particulate phase mercury data represent total dry deposition.
[b] Hoyer et al. 1995; Keeler et al. 1995
[c] Fitzgerald et al. 1991
[d] Lamborg et al. 1995

Adapted from Scherbatskoy et al. (1997).

♦ *Average mercury concentration in precipitation.* Levels appeared to be typically higher in the summer than the winter. Partial data from 1994 suggest that the pattern observed in 1993 is typical for this area. Based on meteorological data, precipitation events with the highest mercury levels during the year were associated with regional transport from the south or west; transport from the west occurred only during the summer months (Burke et al. 1995). The observed mercury levels are low; studies have reported mercury concentration in precipitation generally less than 100 ng/L in areas not directly influenced by emission sources. The type of mercury in precipitation was not quantitatively determined (Scherbatskoy et al. 1997); however, other studies of precipitation found mercury to be in the inorganic (Hg^{+2}) form, probably as mercuric chloride (Burke et al. 1995), with only 2 to 10 percent in the organic (methyl) form (Bloom and Watras 1989; Driscoll et al. 1994).

♦ *Yearly deposition of mercury.* Deposition to the entire Lake Champlain Basin, not just to surface water, was estimated from precipitation (wet deposition) and dry deposition data. Total annual mercury deposition was not very different from that observed at other U.S. locations (Table IV-6). Dry deposition was calculated by using the same monthly proportion of gas deposition to gas concentration reported in Lindberg et al. (1992). Deposition of particulate phase mercury was not a significant source of atmospheric mercury loadings when compared to deposition of mercury in precipitation and from the gas phase. The atmospheric mercury particulate concentration in the area (0.011 ng/m^3) was much lower than the gas concentration (1.9 ng/m^3); therefore, the estimate of mercury dry deposition was based solely on gaseous mercury (which may be an underestimate of deposition to some extent). As shown in Figure IV-7, the annual dry deposition is 5.7 μg mercury/m^2 (with levels higher in the summer than the winter). Mercury deposition in precipitation for 1993

TABLE IV-6
Comparison of Annual Mercury Deposition Estimates [a]

Location	Estimated Wet Deposition (µg/m²/year)	Estimated Dry Deposition (µg/m²/year)	Total Mercury Deposition (µg/m²/year)
Lake Champlain basin[b]	9.27	5.7	14.97
Michigan[c]	5.5-13.0	NA	NA
Little Rock Lake, WI[d]	4.5 ± 2 from rain 2.3 ± 0.3 from snow	3.5 ± 3	10.3 ± 3.6
Minnesota and Northern Wisconsin[e]	NA	NA	12.5

NA = not available

[a] Methods and assumptions for estimating these values varied with studies.
[b] Scherbatskoy et al. 1997   [d] Fitzgerald et al. 1991
[c] Hoyer et al. 1995   [e] Engstrom et al. 1994; Swain et al. 1992

was 9.27 $\mu g/m^2$, with deposition higher in the summer (1 $\mu g/m^2$/month) compared to winter (0.2 $\mu g/m^2$/month). The pattern for mercury deposition in precipitation is probably a result of higher mercury concentrations and higher amounts of rain during the summer; however, insufficient data are available to determine the source of the increased mercury concentration in the summer.

Atmospheric mercury can also enter the lake from snowmelt, which adds higher concentrations of mercury to the rivers emptying into Lake Champlain. The total mercury concentration at three river sampling sites increased two- to six-fold during the peak snowmelt event as compared to the mean levels over the course of the year (Scherbatskoy et al. 1997).

Because the Lake Champlain basin has such a large ratio of watershed to lake surface area, it is important to understand the deposition and cycling of atmospheric pollutants by the largest categories of land use, forests and agriculture, prior to their entry into the lake in runoff. Unlike the Great Lakes watershed, which has relatively more lake surface area, Lake Champlain's water surface area makes up only five percent of the basin area. Therefore, it is important to understand mercury cycling through the terrestrial, atmospheric, and aquatic systems of the Lake Champlain Basin, as ongoing studies are beginning to address.

SOME PROGRAMS RELATED TO TOXICS EMISSIONS AND REDUCTION IN LAKE CHAMPLAIN

Some programs by states have been established to address toxics reduction and to identify and control source emissions in the surrounding region. These efforts may have important impact on atmospheric deposition to Lake Champlain basin. Some of these programs are highlighted below:

♦ The State of New York recently began a program for reducing toxics through a multi-media approach. The Multimedia Program for Pollution Prevention, when fully implemented, will integrate environmental protection programs across all "media," such as air, water, and land, to correct the problem with single media programs.

♦ The State of Vermont conducts a regulatory program for the sources of about 288 hazardous air contaminants (carcinogens, chronic systemic toxicants, and short-term irritants). Hazardous Ambient Air Standards are established for each of these contaminants, with requirements imposed on new and existing sources (excludes fossil fuel combustion) emitting any of these contaminants in excess of a pre-determined "action level" for each pollutant.

♦ New York and Vermont established a Permit Exchange Agreement in accordance with the 1988 Memorandum of Understanding, in which both states are informed of permitted projects in the basin. It allows the affected public to participate in the comment and review process for the permits. Potential toxics sources subject to this agreement include air pollution sources within 80 km of each state border that annually emit 50 tons of volatile organic compounds, sulfur dioxides, nitrogen oxides, carbon monoxide, or particulate matter, or 5 tons of lead, and/or are subject to Title V of the CAA.

Addressing Toxic Contamination Reduction in Lake Champlain

The Lake Champlain Basin Program (LCBP) (see sidebar) has been the institutional framework for coordinating the development of a comprehensive pollution prevention, control and restoration plan for the future of Lake Champlain. The final plan was released in October 1996 (LCBP 1996), following public meetings that allowed interested parties to comment on the an earlier plan. It is anticipated that the objectives of the final plan will be implemented by the Lake Champlain Steering Committee, which is represented by environmental officials from New York, Vermont, and Quebec.

One major issue addressed in the plan is the prevention of pollution from toxic substances in order to protect public health and the Lake Champlain ecosystem. Implementation of the plan will require coordination along all levels of government, organizations, and individuals. The plan identified the following major technical and policy issues involved in determining the most appropriate and cost-effective actions to reduce toxic contamination of Lake Champlain.

Lake Champlain Basin Program

The Lake Champlain Special Designation Act, sponsored by senators from Vermont and New York, was signed in 1990 and states that Lake Champlain is a resource of national significance. The intent of the Act is to create a comprehensive plan for protecting the future of Lake Champlain and its watershed. The coordination of the activities stated in the Act is the responsibility of the Lake Champlain Basin Program (LCBP), which is jointly administered by the U.S. EPA, the States of Vermont and New York, and the New England Interstate Water Pollution Control Commission. EPA was given $10 million in funds for five years to develop a comprehensive pollution prevention, control, and restoration plan for Lake Champlain; the final plan was released in 1996. Other cooperating agencies include the U.S. Fish and Wildlife Service, U.S. Department of Agriculture, U.S. Geological Survey, NOAA, and National Park Service. Formal involvement of Quebec is through the Lake Champlain Steering Committee.

♦   *Define scope of toxics reduction effort.* Research is needed to define the extent of problems related to toxic pollution in tributaries and in the air. Efforts should be made to improve source identification, with attention given to reducing both nonpoint and point sources through all media and remediating current sources of contamination throughout the Basin.

♦   *Focus efforts on Lake Champlain pollutants of concern and sites of concern.* The List of Toxic Substances of Concern was established by LCBP, which identified mercury and PCBs as Group 1 chemicals and meriting highest priority for management action (see sidebar). These two pollutants are found in the sediment, water, and biota at levels above appropriate standards or guidelines in Lake Champlain. Because of limited resources to study and monitor toxic substances, assessments should focus on specific sites where contamination is known.

> **Toxic Substances of Concern in Lake Champlain by Priority Group**
>
> **Group 1:** PCBs, mercury
>
> **Group 2:** Arsenic, cadmium, chromium, dioxins/ furans, lead, nickel, PAHs, silver, zinc
>
> **Group 3:** Ammonia, persistent chlorinated pesticides, phthalates, chlorinated phenols, chlorine, copper
>
> **Group 4:** Other contaminants known to be used or known to occur in the Basin (e.g., volatile organic compounds such as benzene, pesticides such as atrazine, strong acids and bases)
>
> Source: LCBP 1996.

♦   *Identify sources and quantify loads of toxic substances.* Efforts to determine sources of toxic substances within Lake Champlain have been initiated, and few "active" sources have been identified. Two major information gaps in this area that need to be addressed include the extent of contamination from outside the basin, and the role of historical sources (e.g., discharged lead batteries released into the waterbody) and contaminated sediment.

♦   *Adopt strategy to prevent pollution.* Pollution prevention techniques (e.g., source reduction) may be used to achieve reductions at the source of the problem, and eventually reduce pollutants in the lake. Vermont and New York have initiated programs to accomplish this goal, although these programs are not yet integrated into the existing pollution control programs.

♦   *Establish firm and defensible toxic reduction goals.* The current chemical-by-chemical approach to managing pollution in Lake Champlain cannot account for the impact of cumulative or combined effects, and does not protect against unregulated (and potentially more toxic) chemicals entering the lake; therefore, the reduction strategy should be expanded to address toxic substances that do not yet exceed human health standards or cause measurable impacts within the basin.

In addition, as part of these efforts, relevant information gathered from other programs, such as those initiated in the Great Lakes, should be applied to Lake Champlain. As discussed in Section IV.A, the Great Lakes Water Quality Agreement Parties adopted a long-term goal for virtual elimination of sources of specific pollutants. This effort demonstrates the importance of

binational cooperation to address concerns related to reducing toxic emissions in the Great Lakes, as well as in Lake Champlain.